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Capital and Operating Costs of Selected Air Pollution Control Systems

GARD, Inc, Niles, Ill

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16. ABSTRACT

The purpose of this manual is to provide capital, operating, and maintenance costs for air pollution control systems. Capital costs are provided for component equipments, such as ductwork, dampers, heat exchangers, mechanical collectors, fans, motors, stacks, cooling towers, pumps, and dust removal equipment. Five types of control devices are included: (1) high voltage electrostatic precipitators, (2) venturi scrubbers, (3) fabric filters, (4) thermal and catalytic incinerators, (5) adsorbers. Operating and maintenance costs are provided for complete systems. A discussion of the control devices and factors affecting costs is included, along with design parameters for 27 industries. The life cycle cost analysis technique is briefly described and an example of the cost estimating methodology is given. In preparing this manual, the main objective was to "break-out" the individual component costs so that realistic system cost estimates can be determined for the design peculiarities of any specific application. Accuracy of the cost data presented is generally ± 20%.

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by

M.L. Kinkley and R.B. Neveril

GARD, Inc.
7449 North Natchez Avenue
Niles, Illinois 60648

Contract No. 68-02-2072

EPA Project Officer: Frank Bunyard

Prepared for

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Section 1

INTRODUCTION

1.1 PURPOSE OF MANUAL

One of the aims of the U. S. Environmental Protection Agency (EPA) is to provide guidelines and technical assistance to state and local regulatory agencies in the abatement of air pollution. The purpose of this manual is to assist those agencies in estimating the cost of air pollution control systems for the various manufacturers and processors who must comply with the existing and future standards and codes. At present, literature is available which gives generalized cost data for control systems based on industry averages; however, this cost data has a wide range of magnitude due to the variety of installations. In some cases, the cost of the control device itself may only represent 25 percent of the total capital costs while in other cases, it may be as high as 90 percent. These differences in costs can be attributed to the cost of auxiliary equipment, method of controlling the source (direct exhaust or canopy hood, etc.), physical location of control equipment with respect to the source, local code requirements, characteristics of gas stream, plant location, and many other influencing factors. In preparing this manual, the main objective was to "break out" the individual component costs so that realistic system cost estimates can be determined for any specific application based on the peculiarities of the system.

In addition to capital costs, methods for estimating the operating and maintenance costs are provided for each type of control system. A cost comparison methodology is also discussed whereby these recurring costs, together with the capital or first costs, can be evaluated to determine the long term advantages of one system over another.

1.2 ORGANIZATION OF MANUAL

The cost estimating procedures and cost curves in this manual are provided for those systems utilizing the following control devices:

1) High voltage electrostatic precipitators
2) Venturi scrubbers
3) Fabric filters
4) Thermal and catalytic incinerators
5) Adsorbers.

A description of the operation of these devices and the auxiliary equipment required in a completely integrated pollution control system is contained in Section 2. This description outlines the various design options available to the engineer and the influence these options have on the total system cost. A list of the design parameters for the various control devices is also cross-referenced to the applicable industries and pollutant sources that use these systems.

Section 3 describes the procedures used in estimating the costs of a control system with an example of a typical application which can be controlled by any one of three possible control devices. The selection of the most economical system is determined by a life-cycle cost analysis of the three possible systems. The methods and procedures, demonstrated in the example, are applicable to all industries where the control of emissions is provided by these five control systems.

The basic cost curves for the control devices and auxiliary equipment are contained in Section 4. These costs represent equipment, installation, operating, and maintenance costs based on a reference date of December, 1975 and are estimated to be accurate to ± 20 percent, on a component basis, except where noted. A method of extrapolating the costs to a future date is discussed in Section 5.

Section 2

DESCRIPTION OF CONTROL SYSTEMS

The methods of gas cleaning used in industry today can be categorized by the technique in which the gas or particulate is removed. These techniques include: (1) electrostatic precipitation, (2) fabric filtration, (3) wet scrubbing, (4) incineration, and (5) adsorption. The properties and characteristics of the particular gas stream will generally dictate which technique of gas cleaning is appropriate; however, in some cases, several techniques may be suitable and the selection of one type in lieu of the others may be based on efficiency and/or costs (both capital, maintenance, and operating).

Whichever technique is selected for a particular application, a certain amount of auxiliary equipment must be utilized with the control device for the efficient operation of the gas cleaning system. The arrangement of these components with respect to the control device is shown in Figure 2-1. The types of auxiliary equipment required will depend on the application; i.e., hot processes may require pre-coolers before the control device; the addition of moisture may be required for proper operation of the control device, etc. The following description of the five control systems is designed to provide the user with the basic concept of the operation of the control device, the parameters required to size and cost the control device, and the required auxiliary equipment, with costs, necessary for proper operation of the gas cleaning system.

2.1 HIGH VOLTAGE ELECTROSTATIC PRECIPITATOR SYSTEMS

2.1.1 General Description

Gas cleaning by electrostatic precipitation is particularly suited for gas streams which can be easily ionized and which contain either liquid or solid particulate matter. The method of removal consists of passing the

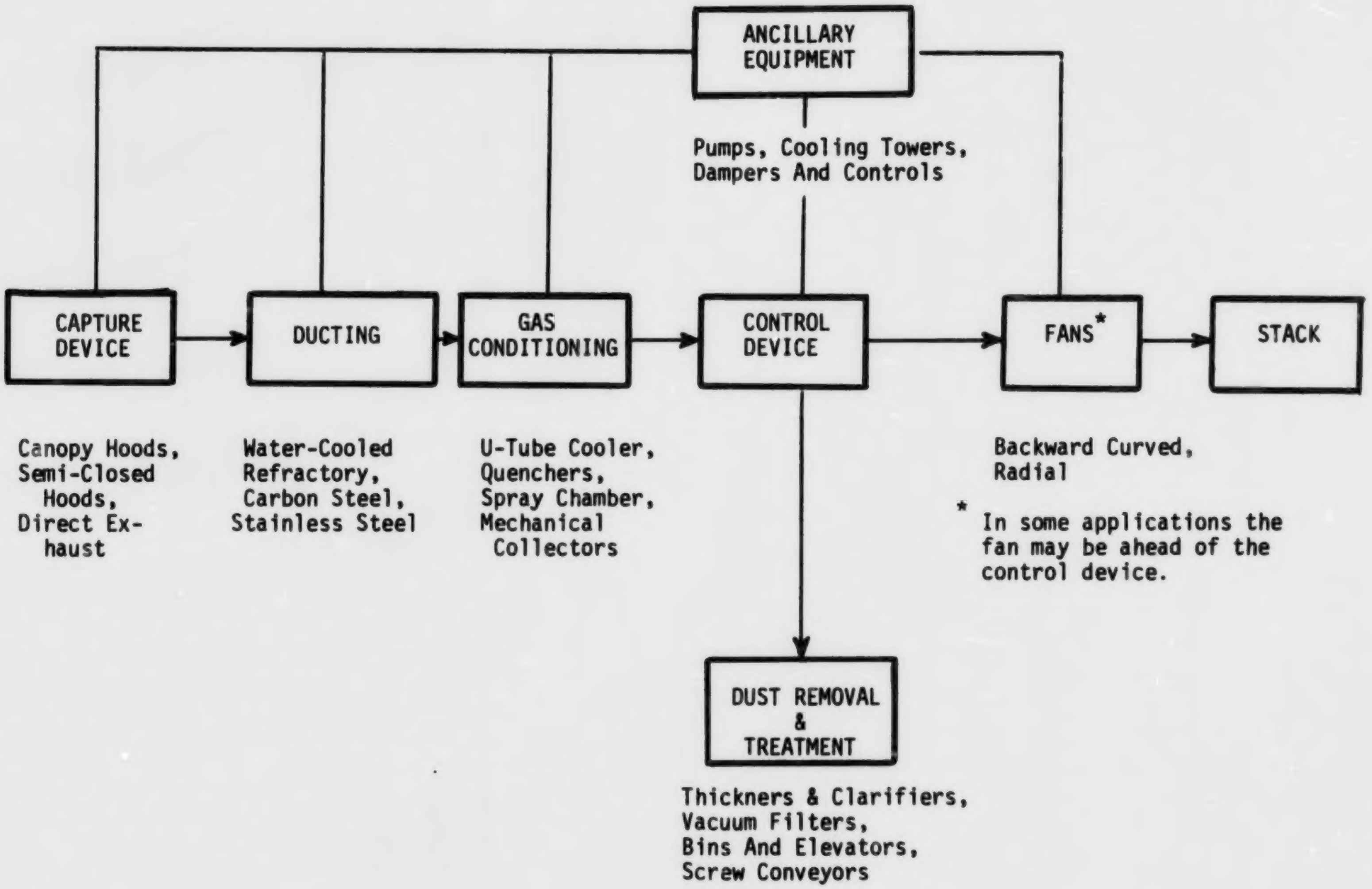

ANCILLARY EQUIPMENT
Pumps, Cooling Towers, Dampers And Controls
CAPTURE DEVICE
DUCTING
GAS CONDITIONING
CONTROL DEVICE
FANS*
STACK
Canopy Hoods, Semi-Closed Hoods, Direct Exhaust
Water-Cooled Refractory, Carbon Steel, Stainless Steel
U-Tube Cooler, Quenchers, Spray Chamber, Mechanical Collectors
Backward Curved, Radial
* In some applications the fan may be ahead of the control device.
DUST REMOVAL & TREATMENT
Thickners & Clarifiers, Vacuum Filters, Bins And Elevators, Screw Conveyors

Figure 2-1 CONTROL SYSTEM FLOW CIRCUIT

particle-laden gas through an electrostatic field produced by a high-voltage electrode and a grounded collection surface. The gas is ionized by the high voltage discharge and the particulate matter is charged by the interaction of the gas ions. The particles migrate to the collecting surface which has an opposite polarity and are neutralized. The adhesive properties of the particles and the action of the electrical field keep the particles on the collecting surface and inhibit re-entrainment. The particles are removed by rappers or by other mechanical devices that vibrate the collector surface and dislodge the particulate, which drops by gravity to hoppers. Usually this is accomplished during normal operation, however, in cases where severe re-entrainment is a problem, sections of the precipitator may be isolated during rapping. The particulate matter is removed from the hoppers periodically by either pneumatic or mechanical screw conveyors.

Electrostatic precipitators are used extensively on large volume applications where the fine dust and particulate is less than 10-20 microns in size with a predominant portion in the sub-micron range. The precipitators can achieve high efficiencies (in excess of 99%) depending on the resistivity of the particulate matter and the characteristics of the gas stream. Wet or dry particulate can be collected including highly corrosive materials if the units are suitably constructed. Precipitators can be used at high temperatures (up to 1000°F) but are normally operated at temperatures below 700°F. The static pressure drop through the units is low, usually up to one-half inch W.G., for units operating at normal gas velocities (2-8 feet per second). The initial capital cost of electrostatic precipitators is high; however, operating (utility) and maintenance costs are reasonably low. Safety precautions are always required since the operating voltages are as high as 100,000 volts. The overall size of electrostatic precipitators is comparable to fabric filters (baghouses) and space requirements are an important factor in the layout and design of the facilities.

2.1.2 Cost Factors

The cost of the basic electrostatic precipitator is a function of the plate area which, in turn, is a function of the required efficiency. The relationship of the plate area to efficiency can be shown by the Deutsch equation:

$$E = 1 - e^{\left[-w\frac{A}{Q}\right]}$$

where E = collection efficiency

w = drift velocity, fps

A = plate area, ft^2

Q = flow rate, cfm

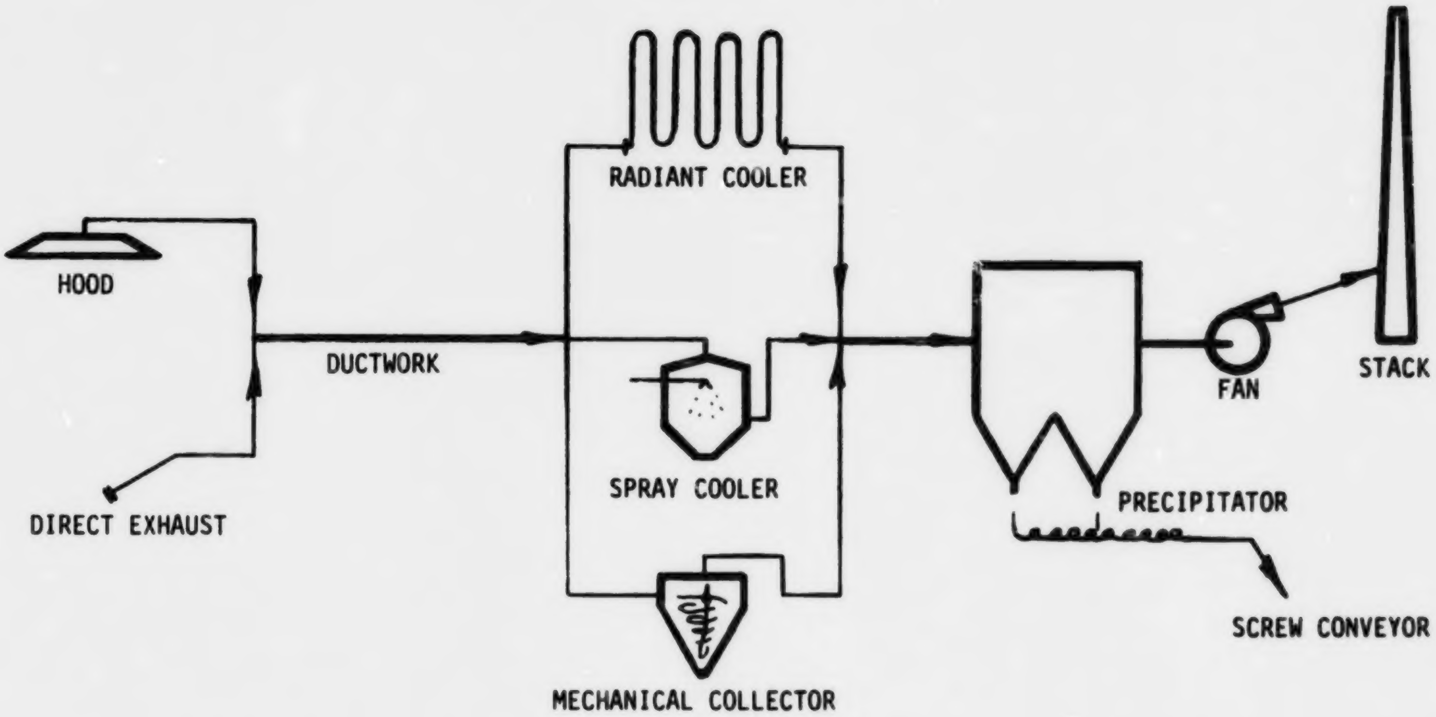
The electrical characteristics of the dust, quantified by the drift velocity, as shown in the Deutsch equation, have a large effect on the collection efficiency and plate area, and consequently, on the cost of the precipitator. The resistivity of the dust varies with the temperature and moisture content of the gas, therefore, in some applications, auxiliary equipment may be required to precondition the gas stream prior to entering the precipitator. The addition of moisture in the gas stream together with low operating temperatures will necessitate insulating the precipitator to prevent condensation and subsequent corrosion problems. The cost of the basic precipitator is therefore separated into insulated and non-insulated units. Special cost factors can be incurred in the type of power supply such as automatic voltage control, number of individual sections energized, type of rectifier, etc., and also, in special materials of construction and special plate design. These factors are additive costs to the basic collector price and represent custom features either required by the process or by the buyer's specifications. For most applications, the cost curves presented in this manual are sufficient.

2.1.3 Auxiliary Equipment

Figure 2-2 illustrates schematically the types of auxiliary equipment that would be used in a gas cleaning system incorporating electrostatic precipitators. These include the capture device, ductwork, mechanical collectors, coolers, spray chambers, fans, dust removal, and stacks. The use of all or only some of this auxiliary equipment will depend on the particular application and pollutant source. In general, all systems will require a capture device, ductwork, and a fan. The capture device can be either a round or rectangular hood located near the pollutant source or it can be directly connected to the source as, for instance, a kiln or furnace. These devices are usually refractory lined, water-cooled, or simply fabricated from carbon steel depending on the gas stream temperatures. Refractory or water-cooled capture devices are used where wall temperatures exceed 800°F; carbon steel is used for lower temperatures.

Ducting has several effects on the sizing and costing of a control system. In addition to conveying the dust-laden stream to the control device, the ductwork can act as a heat exchange means for cooling of hot gases. Also, it always adds flow resistance or pressure losses that result in added horsepower for the fan.

The four basic types of ducting can be classified as carbon steel, stainless steel, water cooled, and refractory. The differentiation between types is not necessarily based on construction alone but rather on the capability of each to transport gases at different temperatures. Water-cooled and refractory ducts can convey gases at any temperature, but are economically used at gas temperatures above 1500°F. Stainless steel ducts are generally used with gas temperatures between 1150°F and 1500°F or where the corresponding wall temperature is below 1200°F. Carbon steel ducts are used at gas temperatures


RADIANT COOLER
HOOD
DUCTWORK
DIRECT EXHAUST
SPRAY COOLER
MECHANICAL COLLECTOR
PRECIPITATOR
FAN
STACK
SCREW CONVEYOR

CONTROL DEVICE AND TYPICAL AUXILIARY EQUIPMENT

Figure 2-2 ELECTROSTATIC PRECIPITATOR CONTROL SYSTEMS

below 1150°F or where the wall temperature is less than 800°F. In the event of corrosive gases, stainless steel ducts can be used at lower temperatures.

For cold processes, carbon steel ducts are used exclusively for non-corrosive gases. In designing ducts, a savings in the size of the ducts (increasing velocity) will eventually be compensated for in fan horsepower, therefore, the design velocity of the gas stream is maintained at a suitable conveying velocity for the type of dust. Typical velocities for industrial dusts can be listed as follows:

DUST TYPE	DUCT VELOCITY, fpm
1) Light Density - gases, smokes, zinc and aluminum oxide fumes, flour, and lint.	2000
2) Medium/Light Density - grain, sawdust, plastic and rubber dusts.	3000
3) Medium/Heavy Density - iron and steel furnace dusts, cement dusts, sandblast and grinding dusts, and most heavy industry dusts.	4000
4) Heavy Density - metal turnings, lead and foundry shakeout dusts.	5000

Since the type and configuration of the capture devices and ductwork are so varied, the cost of these items must be estimated according to size, type and materials of construction, and plate thicknesses. For ducting, the costs are developed on a per lineal foot basis and for hoods the costs are based on the surface area in square feet.

Mechanical collectors, such as cyclones, are used in some cases as pre-cleaners to remove the bulk of the heavier dust particles. These devices operate by separating the dust particles from the gas stream through the use of centrifugal force. Construction is such that centrifugal force is exerted on the gas stream through the use of a tangential inlet, producing a downward vortex. The particles impinge on the sides of the cyclone and are removed from the bottom. The gas stream changes direction at the base of the cyclone and exits in an upward vortex through an axial outlet at the top of the cyclone. Cyclones are available as combinations of large single-cyclones or as units having multiple tubes for higher efficiencies. For the purpose of precleaning, cyclones can remove the majority of dust particles above 20 microns in size to reduce the loading and wear on the control device. The size of a cyclone is usually based on an inlet velocity of approximately 3600 fpm, and therefore the cost of the cyclone is based on inlet area size. Other cost factors include materials of construction, plate thickness, supports, and hoppers.

Dust removal from collectors (baghouses, precipitators, cyclones) can be accomplished intermittently by manual means or continuously by screw conveyors. For applications having light dust concentrations, the collected dust is stored in the hoppers of the control device and periodically emptied through a valve for disposal by truck or local transport. For heavy dust loading, screw conveyors are generally used to continuously remove the dust as it is collected. The cost of continuous removal equipment is based on the diameter of the screw conveyor and its overall length.

Coolers and spray chambers are used with electrostatic precipitators for systems handling hot gases to reduce the gas volume to the collector; or, in the case of spray chambers, to add moisture to the gas stream to reduce the resistivity and enhance the electrical characteristics of the dust. Dry-type coolers used expressly for cooling the gas stream without adding water generally consist of radiant "U-tubes" of 30 to 60 feet in height and between 12 and 36 inches in diameter. These tubes are manifolded together both in parallel and in series to provide sufficient heat transfer surface to reduce the gas temperature to a value compatible with efficient precipitator operation. The number of required "U-tubes" in series depends on the inlet gas temperature and the required outlet gas temperature. The number of "U-tubes" in parallel depends on the volume of gas being handled and the desired gas velocity per tube. The cost of a cooler, therefore, can be estimated from the number of modular U-tubes of a given diameter and height based on the desired temperature drop and flow rate for the particular application.

Wet-type coolers or spray chambers cool and humidify the gas by the addition of water sprays in the gas stream. For effective evaporation, a cylindrical chamber is usually provided to reduce the gas stream velocity at the point at which the water is injected and where evaporation occurs. The diameter and length of the chamber is dependent on the maximum droplet size of the sprays, and the relative temperature and velocity of the gas stream and water droplets. Generally, gas stream velocities are maintained at approximately 10 feet per second with inlet spray water pressures of approximately 100 psig. Increasing the water pressure results in reduced water droplet size, faster evaporation, and consequently, smaller chambers. The cost of spray coolers is based on the size and volume of the chamber, materials of construction and the water flow rate.

Centrifugal fans, having either backward curved or radial tip blades, are used almost exclusively to transport the dust-laden gases through the system. The backward curved fan provides the highest efficiency, but because of its inherent design, must be used downstream of the control device where the gas stream is relatively dust-free. These fans are categorized into Classes I through IV according to maximum impeller speeds and pressures. The cost of the fan is based on its construction, class, volume, and pressure delivered at standard conditions. The radial tip fan, sometimes referred to as the industrial fan, operates at a lower efficiency, but is capable of handling dusty gas streams and can be used upstream of the control device. The impeller of this fan consists of flat radial paddles which can be modified to include wear plates for abrasive dust applications. These fans can also be operated at high temperatures. The cost of this type of fan is based on materials of construction, total volume, and pressure delivered at standard conditions.

The cost of the motor and motor starter for centrifugal fans is related to the fan speed, total system pressure, gas volume flow rate, and selected motor housing. Fan speeds are chosen from a continuum, with aid of the fan laws, to provide a desired head at a prescribed flow. Motor speeds are chosen from a set of perhaps only five discrete choices (Table 4-7). Since belts and pulleys are routinely used, fan speed and motor speed should be selected as close to each other as possible. The motor housings should be chosen for the particular environment in which it will be operating. Drip-proof motors should be used in areas which are weather protected and relatively clean. Totally enclosed motors should be used in dusty areas or areas exposed to weather and severe splashing. Explosion-proof motors must be used in hazardous atmospheres where explosive fumes are present.

Stacks are provided downstream of the fans for dispersion of the exhaust gases above the immediate ground level and surrounding buildings. Minimum stack exit velocities should be at least 1.5 times the expected wind velocity; or for instance, in the case of 30 mph winds, the minimum exit velocity should be 4000 fpm. Small stacks are usually fabricated of steel, which may be refractory lined, and are normally limited to exit velocities of approximately 9000 fpm. Tall stacks, over 200 feet, can be designed with liners of steel or masonry. The cost of stacks is based on diameter, material thickness and type, height, and whether a liner is provided.

2.2 VENTURI SCRUBBER SYSTEMS

2.2.1 General Description

Venturi type scrubbers are capable of providing high efficiency collection of sub-micron dusts which are not easily collected by other types of scrubbers. Basically, the scrubber is constructed with a converging section of the venturi to accelerate the gas stream to a maximum velocity at the throat section where impaction with the scrubbing fluid or liquor occurs. Fine droplets of the scrubbing liquor are atomized as a result of this interaction and the relative velocities between the dust particles and droplets cause collision and agglomeration as they proceed through the throat section. Further agglormeration occurs as the gas stream is decelerated in the diverging section of the venturi, thus producing droplets with the entrapped dust of a size easily removable by mechanical means.

The pressure drop through the venturi is a function of gas stream throat velocity and scrubbing liquor flow rate, which in turn have been chosen for a desired collection efficiency on a given dust. The smaller the dust particle size, the higher the pressure drop required. As the pressure drop is increased, finer droplets are atomized to interact with the dust particles through impingement and agglomeration, with the consequent increase in collection efficiency. Increasing the pressure drop can be accomplished by either increasing the gas stream throat velocity, increasing the scrubbing liquor flow rate or both. Fundamentally, the relationship between pressure drop and collection efficiency is the same for all types of venturi scrubbers irrespective of the size, shape or general configuration of the scrubber. Venturi scrubbers are normally operated at pressure drops of between 6 and 80 inches W.G. depending on the characteristics of the dust, and at liquor flow rates of 3 to 20 gpm per 1000 ACFM. The collection efficiencies range from 99+% for one micron or larger sized particles to 90 to 99% for particles below one micron size.

A separator for removal of the agglomerates from the gas stream is provided downstream of the scrubber. These separators are usually of the cyclone type where the gas stream and agglomerates are given a cyclonic motion which forces the liquid and particles to impinge on the walls of the separator by centrifugal force. The separator normally consists of a cylindrical tank with a tangential inlet located at the lower side of the tank and an exhaust outlet located at the top of the tank on the centerline axis. A cone bottom with outlet is provided to collect the liquid slurry. The collected particles settle to the bottom of the cone and are removed to the water treatment facility while the cleaner liquid above the sediment is removed and recycled to the scrubber.

For hot processes, a considerable amount of water is vaporized in the scrubber and upstream equipment (e.g., quencher), which must be handled by the fan. Although the gas volume is reduced, a large portion remains as water vapor which results in higher horsepower requirements and in higher operating costs. To alleviate this condition, a gas cooler can be incorporated into the separator to cool and dehumidify the gas stream. Several types of gas coolers are used for this purpose; one type employs spray banks of cooling water followed by impingement baffles while a second type utilizes flooded plates or trays with either perforated holes or bubble caps to permit passage of the gas stream through the bath of cooling water. Several plates or trays can be used in sequential stages to provide the necessary cooling and contact time.

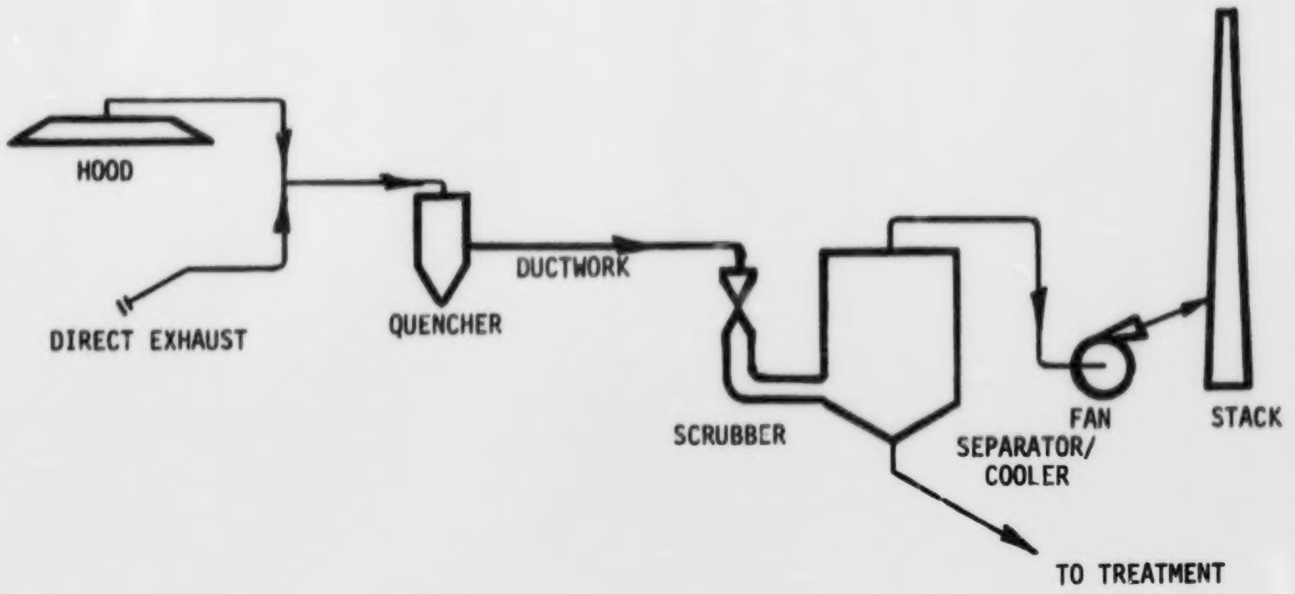
In addition to its ability to remove sub-micron dusts, the venturi scrubber with separator and gas cooler/contactor can also be used as a gas absorber. These units have been used successfully in the removal of acid mists in the chemical industry and the removal of SO_2 and SO_3 in municipal power plant flue gases.

2.2.2 Cost Factors

The cost of the scrubber and separator are based on the volumetric flow rate, operating pressure, and materials of construction. The sizes of the scrubber, separator, and elbow (vertically oriented) are determined from the actual inlet gas volume in acfm and priced accordingly for a basic plate thickness of 1/8 inch. Additional cost factors are provided for different metal thicknesses, fiberglass or rubber liners, manual or automatic venturi throat, and stainless steel construction. The plate thickness for the scrubber and separator is a function of the maximum operating design pressure and shell diameter; therefore, as the volume flow rate and/or pressure drop increase, the metal wall thicknesses must also be increased to prevent buckling. In addition, some allowances for corrosion or erosion are usually added to the design conditions. Typical design parameters for a scrubber and separator are based on a scrubber inlet gas velocity of 3500 fpm and a separator superficial inlet velocity of 600 fpm. For a given flow rate, the internal surface area for the scrubber, elbow and separator can be determined to establish the additive cost of a rubber or fiberglass liner. Likewise, the diameter and height of the separator will determine the volume available for an internal gas cooler.

2.2.3 Auxiliary Equipment

The auxiliary equipment normally associated with venturi scrubber systems is shown schematically in Figure 2-3. These include a capture device and ductwork, a quencher, dust removal and treatment, fan, and a stack. The capture device, ductwork, and stack are the same components used for electrostatic precipitator systems and are discussed in Section 2.1.3. The quencher, used for hot processes, is fundamentally the same as a spray chamber; however, it is much simpler in operation, requires minimum controls, and usually has no


HOOD
DIRECT EXHAUST
QUENCHER
DUCTWORK
SCRUBBER
SEPARATOR/
COOLER
FAN
STACK
TO TREATMENT

CONTROL DEVICE AND TYPICAL AUXILIARY EQUIPMENT

Figure 2-3 VENTURI SCRUBBER CONTROL SYSTEMS

sprays to plug. The objective of using a quencher is to reduce the gas stream temperature to the saturation temperature and this is accomplished by flooding the gas stream with cooling water. Since the quencher is operated with more water than required to reach saturation temperature, outlet gas temperature controllers are not necessary, nor are the banks of spray nozzles which are normally operated by these controllers. Quenchers are usually fabricated from corrosion resistant materials, or are refractory lined, and can be either horizontally or vertically oriented. Costs are based on inlet gas volume and materials of construction. Quenchers also act as a precleaner for larger sized dust particles with the collected slurries being returned to the waste treatment facility.

Waste removal and treatment facilities for both the scrubber and quencher (if used) generally consist of a thickener and vacuum filter or centrifuge. The overflow from the thickener is recycled to the scrubber and quencher while the heavier solids are removed for dewatering by the filter or centrifuge. The costs of thickeners, vacuum filters, and centrifuges are completely covered in the following reports, also listed in Appendix C as source Nos. 119 and 128.

> "Capital and Operating Costs of Pollution Control Equipment Modules", Vol. I and Vol. II, EPA-R5-73-023 a and b, July, 1973. NTIS PB 224-535 & PB 224-536.
>
> "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", EPA 17090 DAN 10/71. NTIS PB 211-132.

Radial tip fans are used almost exclusively in venturi scrubber control systems because of their ability to operate at high pressures and temperatures with abrasive gas streams. With scrubber systems, a certain amount of carryover of dust-laden water droplets can be expected which would be destructive to other types of fans operating at the impeller tip velocities necessary for 20-80 inches W.G. pressures. The radial tip fan can also be protected with wear plates and water sprays (for cleaning blades) for dirty or highly abrasive gas streams. The cost of radial blade fans is a function of the actual volume in cfm and the total pressure delivered based on incremental pressure ranges of 20,40 and 60 inches W.G.. Construction can be either carbon steel for general purposes or stainless steel for corrosive gases. Special linings are also available for unique conditions.

2.3 FABRIC FILTER SYSTEMS

2.3.1 General Description

Gas cleaning by fabric filtration is suited for applications where dry particulates are handled or where water in the process gases is in the vapor stage. The basic filter collector or "baghouse" is capable of operating in excess of 99% efficiency, although satisfactory operation of the system is contingent upon the characteristics of the gas stream and the particulate matter being removed. Basically, the unit consists of compartments containing rows of filter bags or tubes. The particle-laden gas is ducted to each compartment where the gas passes through the bags while the particles are retained on the surface of the bags. The pressure drop across the filter medium increases as the particulate collects on the fabric until a preset time limit is reached, at which time a section is isolated and the entrapped material is dislodged and collected in hoppers located below the filtering area. Baghouses are characterized by the methods used to clean the bags as well as the frequency of bag cleaning. These methods are generally referred to as: 1) shaker type, 2) reverse air, and 3) pulse jet.

The shaker type method of cleaning consists of hanging the bags on an oscillating framework driven by a motor with a timer. The baghouse is separated into several compartments so that at periodic intervals, the gas flow to a compartment is interrupted and the motors and connected frames in the compartment are activated with the subsequent shaking of the bags to remove the particulate. The shaker type mechanisms produce a violent action on the bags and, in general, produce more wear on the bags than other types of cleaning mechanisms. For this reason, shaker type cleaning is used in conjunction with heavier and more durable fabric materials.

The reverse air method of cleaning the bags is accomplished by passing air countercurrent to the direction of the gas flow in normal filtration when the compartment is isolated for cleaning. The reverse air is supplied by a separate fan or in some cases, the pressure differential across the bags can be used to collapse the bags without the aid of a fan. This type of cleaning is used with fragile bags (such as fiberglass) or lightweight bags and usually results in longer life for the bag material.

Bag cleaning by pulse jet is accomplished by the use of compressed air jets located at the top of the bags. Periodically, a blast of compressed air is issued down the bag, rapidly expanding the bag to dislodge the particulate. In some cases, this method of cleaning does not require the isolation of the bags to be cleaned from the filtering process so that extra compartments required for cleaning with the shaker and reverse air type baghouses are not needed. In addition, the pulse jet baghouses can sustain higher filtering velocities through the filter medium (higher air-to-cloth ratios) and therefore the overall size of the baghouse is reduced.

Baghouses are also categorized as to the type of service and frequency of bag cleaning and are generally referred to as either intermittent or continuous duty. Intermittent baghouses are cleaned after filtering is completed; i.e., after the process stream is secured or shut down, usually at the end of each day. These baghouses operate with low dust loadings since they cannot be cleaned while on stream. Continuous baghouses operate indefinitely and cleaning of a portion of the filter occurs at periodic intervals while the process gases are being filtered by the remaining filter area. Continuous duty baghouses are more expensive than the intermittent type due to the accessories required in the cleaning process and the additional filter area required for continuous cleaning.

The location of the baghouse with respect to the fan in the gas stream is also a factor in the capital costs. Suction type baghouses, located on the suction side of the fan, must withstand high negative pressures and therefore are more heavily constructed and reinforced than baghouses located downstream of the fan (pressure baghouse). The negative pressure in the baghouse can result in the infiltration of outside air which can result in condensation, corrosion or even explosions if combustible gases are being handled. In the case of toxic gases, this inward leakage can have an advantage over the pressure type baghouse, where leakage is outward. The main advantage of the suction baghouse is that the fan handling the process stream is located at the clean gas side of the baghouse. This reduces the wear and abrasion on the fan and permits the use of more efficient fans (backwardly curved blade design). However, since the exhaust gases from each compartment are combined in the outlet manifold to the fan the location of compartments with leaking bags is difficult to determine and adds to the cost of maintenance. The outlet manifold from the baghouse is connected to the fans which are usually located at ground level; therefore, a stack is normally required to vent the gas from the fan.

Pressure-type baghouses are generally less expensive since the housing must only withstand the differential pressure across the baghouse. Maintenance is also reduced since the compartments can be entered and leaking bags can be observed with reasonable comfort while the compartment is in-service. With a pressure baghouse, the housing acts as the stack to contain the fumes with the subsequent discharge at the roof of the structure. The main disadvantage of the pressure-type baghouse is that the fan is exposed to the dirty gases where abrasion and wear may become a problem.

The design and construction of baghouses are separated into two groups: standard and custom. Standard baghouses are pre-designed and built as modules which can be operated singly or combined to form units for larger capacity applications. The custom or structural baghouse is designed specifically for an application and is usually built to the specifications prescribed by the customer. The cost of the custom baghouse is much higher than the standard and is used almost exclusively in large capacity (large volume) applications. The advantages of the custom baghouse are many and are usually directed towards ease of maintenance, accessibility, and other customer preferences. In standard baghouses, a complete set of bags are usually replaced in a compartment at one time because of the difficulty in locating and replacing single leaking bags, whereas, in custom baghouses, single bags are accessible and can be replaced one at a time as the bags wear out.

The type of filter material used in baghouses is dependent on the specific application in terms of chemical composition of the gas, operating temperature, dust loading, and the physical and chemical characteristics of the particulate. A variety of fabrics, either felted or woven, are available and the selection of a specific material, weave, finish, or weight is based primarily on past experience. The type of cloth will generally dictate the type of cleaning mechanism to be used in the baghouse. Usually, felted fabrics are used with pulse jet cleaning whereas woven fabrics are used with mechanical shaker or reverse air cleaning. The type of yarn (filament, spun, or staple), the yarn denier, and twist are also factors in the selection of suitable fabrics for a specific application. Because of the violent agitation of mechanical shakers, spun or staple yarn fabrics of heavy weight are usually used with this type of cleaning while filament yarn fabrics of lighter weight are employed with reverse air cleaning. The type of material will dictate the maximum operating gas temperature for the baghouse. Nominal operating temperatures for various fabrics are listed below:

COTTON: 180°F
POLYPROPYLENE: 180°F
NYLON: 200°F
ACRYLIC: 275°F
POLYESTER: 275°F
NOMEX: 425°F
TEFLON: 500°F
FIBERGLASS: 550°F

The superficial face velocity of gas passing through the cloth affects pressure drop and bag life. The fundamental filtering parameters are based on this velocity which is equal to the total actual volumetric flow rate in cubic feet per minute divided by the net cloth area in square feet. This ratio is referred to as the air-to-cloth ratio and is the basis for sizing and costing baghouses. High air-to-cloth ratios will reduce the size of the baghouse (and subsequent cost) while low air-to-cloth ratios will require larger units. The air-to-cloth ratio will also determine the type of cleaning mechanism to be used in the baghouse. Shaker type and reverse air cleaning can be used with air-to-cloth ratios of up to 4 to 1 while pulse jet cleaning can be utilized with air-to-cloth ratios of up to 10 to 1 or higher in special cases. The type of material selected as the cleaning fabric will also dictate the range of air-to-cloth ratios to be used in a particular application; for instance, polyester fabrics are normally used with ratios of up to 3 to 1, while fiberglass is usually limited to 2 to 1. These limiting ratios are the normal "rule of thumb"; however, with light dust loading, these air-to-cloth ratios can be exceeded in some cases.

2.3.2 Cost Factors

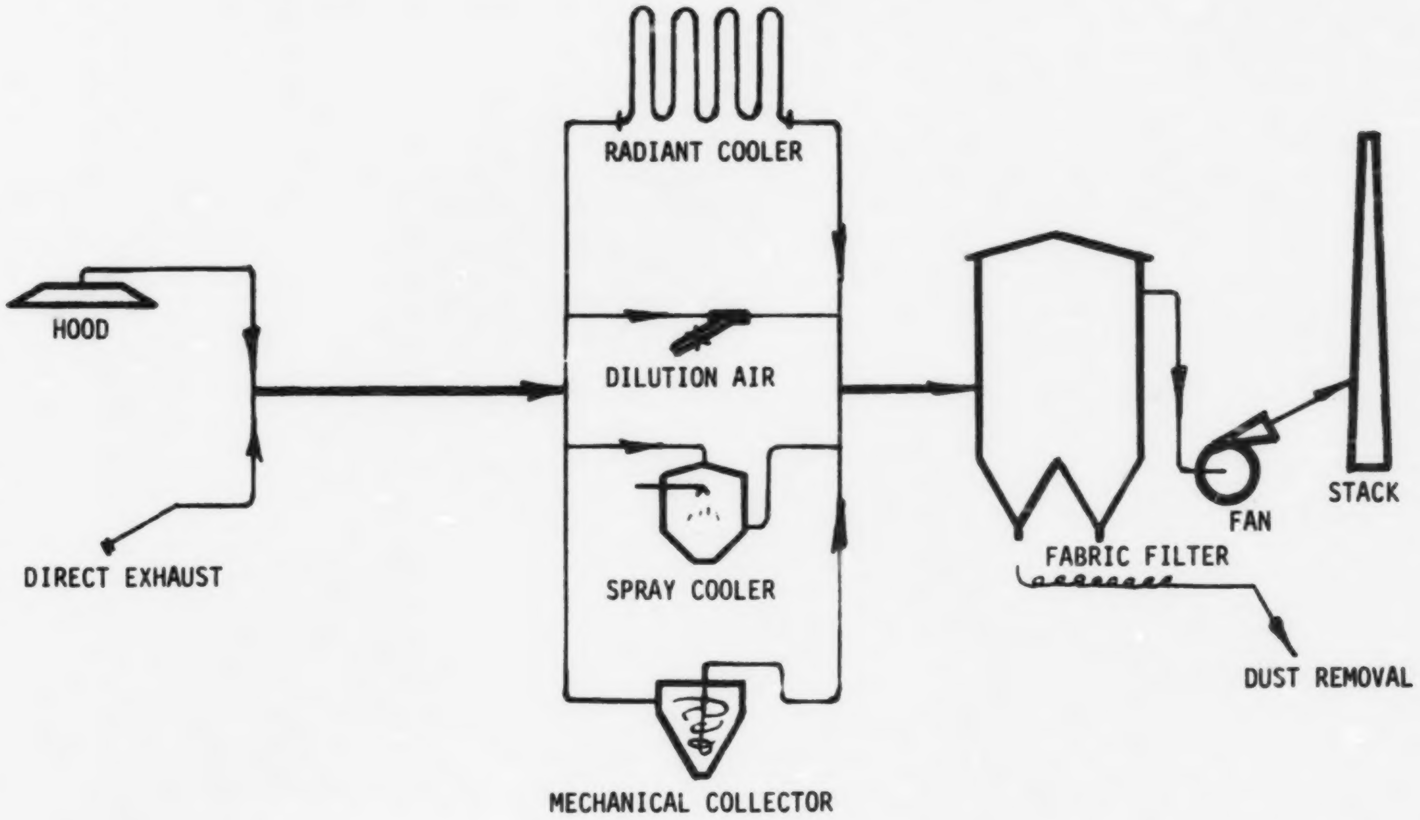
The cost reference for baghouses is based on the net cloth area. Net cloth area is defined as the total filter area available for on-stream filtration exclusive of the filter area in compartments which are isolated for cleaning (in the case of intermittent filters, the net cloth area is actually the gross cloth area). The net cloth area is determined by the air-to-cloth ratio recommended for a particular application, which is principally based on the type of fabric, type of dust, carrier gas composition, and the dust concentration. The cost options of the fabric filter are therefore based on the following parameters as determined by the type of application.

1) Type of fabric and air-to-cloth ratio.
2) Intermittent or continuous duty.
3) Pressure or suction type construction.
4) Standard or custom design.
5) Type of cleaning mechanism.
6) Materials of construction.

2.3.3 Auxiliary Equipment

The typical auxiliary equipment associated with fabric filter systems is shown schematically in Figure 2-4. This equipment includes the capture device, ductwork, radiant coolers, spray chambers, dilution air ports, mechanical collectors, dust removal equipment, fans, and stack. This equipment has been discussed in Section 2.1.3 with the exception of dilution air ports.

Dilution air ports are provided to protect downstream components from


RADIANT COOLER
HOOD
DILUTION AIR
DIRECT EXHAUST
SPRAY COOLER
MECHANICAL COLLECTOR
FABRIC FILTER
FAN
STACK
DUST REMOVAL

CONTROL DEVICE AND TYPICAL AUXILIARY EQUIPMENT

Figure 2-4 FABRIC FILTER CONTROL SYSTEMS

"over-temperature" by diluting the hot gas stream with cooler ambient air. Dilution air cooling requires the least amount of equipment compared to other types of cooling; however, the downstream equipment such as the baghouse, fans, and ductwork are substantially increased in size (and cost) to compensate for the additional air. The components for dilution cooling generally consist of a duct tee, damper, and temperature controller. The damper is continually modulated, inspiring ambient air to maintain the downstream gas temperature at a pre-set level. The cost of the equipment for dilution cooling is based on the duct diameter and represents the cost of ductwork, damper, sensor and controller.

2.4 THERMAL AND CATALYTIC INCINERATOR SYSTEMS

2.4.1 General Description

Gas cleaning by thermal or catalytic incineration is readily adapted to processes that emit combustible gases, vapors, aerosols, and particulates. These systems are used extensively in removing odors and in reducing the opacity of visible plumes from ovens, driers, stills, cookers and refuse incinerators. The principle of operation consists of ducting the exhaust process gases to a combustion chamber which employs either a catalyst bed or direct-fired burners to combust the contaminant gases to carbon dioxide and water vapor. Direct-fired gas burners are most commonly found because of their simplicity and reliability; however, catalytic units do produce combustion at lower temperatures which can result in lower fuel costs. In direct-fired thermal incinerators (afterburners), the contaminated gas stream is delivered to the refractory lined burner area by either the process exhaust system or by a self contained blower. The introduction of the gas stream at the burners insures turbulence and complete mixing with the combustion products at the highest temperatures possible. The gas stream and combustion products then enter the retention chamber at lower velocities to increase residence time and ensure complete oxidation of the combustibles. To reduce fuel costs, recuperative heat exchangers can be provided downstream of the retention chamber to recover some of heat from the exhaust gases by preheating the inlet contaminated gas stream. A second method of recovering heat from the afterburner exhaust is to recycle a portion of this gas to the inlet gas stream. The efficiency of direct-fired afterburners depends on the type and concentration of contaminants in the inlet gases, the operating temperature, turbulence, the mixing of gases in the afterburner, and the residence time. Heat exchangers, when added, increase the thermal efficiency and reduce fuel costs at the expense of higher initial costs.

Direct-fired thermal incinerators can be provided as packaged units for small volume applications which include the basic chamber, fan, and controls. Larger units are usually custom designed or are modifications of standard components integrated into a complete unit. The amount of controls and instrumentation required for these systems will depend on the characteristics of the process gas stream. Steady state processes require the least amount of controls whereas, fluctuating gas streams would require modulating controllers for the burners, recycle gas, etc.. Most units however, require a minimum amount of controls such as safety pilots and flame failure shut-offs, high temperature shut-offs (fan failure), and temperature monitors and recorders. The fans used for these units usually are of the axial flow or low pressure centrifugal type since pressure drops for the incinerator alone are low.

An alternative to the direct-fired thermal incinerator is the catalytic incinerator which utilizes a catalyst bed to oxidize the contaminants to carbon dioxide and water vapor. This reaction takes place at reduced temperatures (650-1200°F) as compared to the direct-fired incinerator (850-1800°F) and, therefore, the fuel costs can be reduced. One of the limitations of the catalytic incinerator, however, is its susceptibility to fouling and degradation by particulates or metal poisons such as zinc, lead, tin, etc. For this reason, the gas streams containing organic vapors or solvents are better suited for catalytic combustion while those containing fumes and smokes should be controlled by the direct-fired incinerator.

The catalytic incinerator consists of the catalyst bed, preheat burners, ductwork, fan, and controls. The preheat burners are required to raise the temperature of the inlet gas stream to a level compatible with the oxidation reaction temperature of the catalyst. To conserve on fuel costs, the preheat burners can be regulated by controllers monitoring the exit gas temperature of the catalyst bed. As the bed temperature increases from heat transferred by the exothermic reaction, the amount of heat supplied by the preheat burners can be reduced accordingly. This can result in a savings of approximately 40-60 percent in fuel costs as compared to the direct-fired incinerator. The catalytic incinerator, however, has a higher maintenance cost than the direct-fired incinerator due to the necessity of periodically cleaning the catalyst bed and the eventual replacement of the bed. Catalytic incinerators are available in packaged units for small volume applications and custom units for larger applications. Heat exchangers are also available which will provide up to 50 percent heat recovery.

2.4.2 Cost Factors

The cost of thermal and catalytic incinerators is based on the actual volume flow rate, and such design factors as whether the unit is a package or custom design, and whether a heat exchanger is used for heat recovery. The basic cost of the incinerators includes the incinerator and base, fan, motor, starter, integral ductwork, controls, instrumentation, and heat exchanger (where applicable). For thermal incinerators, the cost of the units also varies with the designed residence time. Longer residence times will necessitate higher cost equipment due to the longer and larger retention chambers.

2.4.3 Auxiliary Equipment

A minimum of auxiliary equipment is required for thermal and catalytic incinerators since the units are normally self-contained. Usually some ductwork, a fan, and a capture device are required to transport the process gas stream from the source to the control device if the distance is appreciable. A separate fan however is supplied with the incinerator to ensure proper distribution and mixing of the gases in the incinerator. An exhaust stack is also required to disperse the exhaust gases above the level of the surrounding buildings. The cost of these components is covered in Section 2.1.3.

2.5 ADSORPTION SYSTEMS

2.5.1 General Description

Gas cleaning by adsorption is used primarily in the removal of organic liquids and vapors from process streams. The principles of adsorption and the affinity of certain adsorbents for specific compounds are quite complex; however, the process can be considered as the mechanical and chemical bonding of a substance on the surface of an adsorbent. The control system using this principle usually consists of at least two adsorbent beds with one bed on stream adsorbing while the second bed is regenerating. Regeneration is usually accomplished by heating the adsorbent to a high temperature to drive off the adsorbed compounds. Continuous adsorbers have also been devised where adsorption and regeneration take place in different positions of the same bed, which is progressively displaced through the vessel. Some problems that exist in adsorption systems are the result of solids in the process gas stream. Particulate matter in the gas stream can be detrimental to adsorber beds by blinding the adsorbent; therefore, efficient filters must be provided at the inlet to the beds. Corrosion is also a factor in the maintenance of the beds and equipment, and is usually related to the method of bed regeneration. Activated carbon is the most widely used adsorbent in industry, however, other adsorbents such as silica gel, bauxite, and alumina are used for some specific processes. The regeneration of activated carbon adsorption beds is normally accomplished by passing steam through the bed in the opposite direction of the normal gas flow during adsorption. The flow rate, temperature, and pressure of the steam required for regeneration is dependent on the type and characteristics of the adsorbate and the quantity adsorbed. After regeneration, the beds are normally cooled by passing clean air through the carbon before being placed on stream. Fixed bed adsorbers usually consist of at least two beds; one adsorbing while the other is regenerating. If the time for regenerating and cooling is longer than the adsorption time, three beds may be used; one adsorbing, one regenerating, and one cooling. The operations involved with switching beds from the adsorption stage to the regeneration stage can be either manual or automatic. Automatic systems cost more due to the mechanisms and controls required. Carbon adsorbers are supplied as either packaged units for small volume applications or custom designed units for larger applications. The units, as supplied, consist of the adsorber beds, activated carbon, fans or blowers, controls, and the steam regenerator (excluding steam source).

2.5.2 Cost Factors

The cost of carbon adsorbers is based on the weight of activated carbon required. The carbon requirements are determined by the gas flow rate, the type and concentration of the pollutant, the carbon adsorption efficiency for that particular pollutant, and the specific time of adsorption/regneration. Packaged units are priced according to the mode of operation; i.e., automatic or manual while custom designed units for large volume applications are all automatic.

2.5.3 Auxiliary Equipment

Since the adsorbers are usually supplied as self-contained units, the only auxiliary equipment needed would be hoods and ductwork which are discussed in Section 2.1.3.

2.6 APPLICATION TO INDUSTRY

Not all of the five control systems can be applied universally throughout the various industries. For instance, adsorbers are only effective with gaseous pollutants while thermal and catalytic incinerators require combustible particulates and vapors for proper operation. Particulate-laden gas streams which are not combustible must be controlled by precipitators, scrubbers, or baghouses. Precipitators and baghouses are used solely for particulate collection while scrubbers may be used for both particulates and gases (when used as a contactor/absorber). The selection of a control system for a particular process, therefore, may be limited to only one or two types of control devices. Tables 2-1 and 2-2 lists 27 industries with typical sources of pollutants and itemizes the types of control devices with their design parameters that are used to control these sources. Table 2-3 lists the types of solvents and their lower explosive limit that might be expected in the exhaust gases from such sources as spray booths, printing presses, etc.. These solvents are usually recovered through the use of an activated carbon adsorber and, therefore, the carbon adsorption efficiency for each solvent is also provided.

Appendix C provides a cross-reference of literature information applicable to each industry. Appendix D provides a list of associations related to

Table 2-1 INDUSTRY POLLUTANT SOURCES AND TYPICAL CONTROL DEVICES

INDUSTRY	SOURCE	CONTROL SYSTEM	CAPTURE DEVICE	TYPICAL GAS FLOW DESIGN RATE	TYPICAL GAS TEMPERATURE
1) Brick Manufacturing	1) Tunnel kiln 2) Crusher, mill 3) Dryer 4) Periodic kiln	1) Scrubber, baghouse precipitator 2) Baghouse, scrubber 3) Same as 1 4) Same as 1	1) Direct tap 2) Canopy hood 3) Same as 1 4) Same as 1	1) Combustion air fan capacity 2) 250 fpm hood face 3) Same as 1 4) Same as 1	1) 200-600F 2) 70F mill 3) 250F 4) Same as 1
2) Castable Refractories	1) Electric arc 2) Crusher, mill 3) Dryer 4) Mold and shakeout	1) Baghouse, scrubber 2) Same as 1 3) Same as 1 4) Same as 1	1) Direct tap 2) Canopy hood 3) Direct tap 4) Canopy hood	1) Infilt. air 2) 250 fpm hood face 3) Fan capacity 4) Same as 2	1) 3000-4000F 2) 70F 3) 300F 4) 150F
3) Clay Refractories	1) Shuttle kiln 2) Calciner 3) Dryer 4) Crusher, mill	1) Baghouse, precipitator, scrubber 2) Same as 1 3) Same as 1 4) Baghouse, precipitator	1) Direct tap 2) Same as 1 3) Same as 1 4) Canopy hood	1) Fan capacity 2) Same as 1 3) Same as 1 4) 250 fpm hood face	1) 150-800F kiln 2) Same as 1 3) 250F 4) 70F
4) Coal-fired Boilers	1) Steam generator	1) Precipitator, Scrubber	1) Direct tap	1) Induced draft fan capacity	1) 300F
5) Conical Incinerators	1) Incinerator	1) Scrubber	1) Direct tap	1) Combustion air rate	1) 400-700F
6) Cotton Ginning	1) Incinerator	1) Scrubber	1) Direct tap	1) Combustion air rate	1) 500-700F
7) Detergent Manufacturing	1) Spray Dryer	1) Scrubber, baghouse	1) Direct tap	1) Fan capacity	1) 180-250F

Table 2-1 INDUSTRY POLLUTANT SOURCES AND TYPICAL CONTROL DEVICES (cont'd)

INDUSTRY	SOURCE	CONTROL SYSTEM	CAPTURE DEVICE	TYPICAL GAS FLOW DESIGN RATE	TYPICAL GAS TEMPERATURE
8) Feed Mills	1) Storage bins 2) Mills/grinders 3) Flash dryer 4) Conveyors	1) Baghouse, scrubber 2) Same as 1 3) Same as 1 4) Same as 1	1) Direct tap 2) Canopy hood 3) Direct tap 4) Canopy hood	1) 250 fpm canopy hood face velocit 2) Same as 1 3) Air heater flow rate (dryer) 4) Same as 1	1) 70F 2) 70F 3) 170-250F 4) 70F
9) Ferroalloy Plants a) HC Fe Mn b) 50% Fe Si c) HC Fe Cr	1) Submerged arc furnace (open) 2) Submerged arc furnace (closed) 3) Tap fume	1) Scrubber, baghouse, precipitator 2) Scrubber 3) Same collector or baghouse	1) Full or canopy hood 2) Direct tap 3) Canopy	1) 2500-5500 scfm/mw with scrubber 2) a) 220, b) 180, c) 190 } scfm/mw 3) 200 fpm/ft^2	1) 400-500F open arc 2) 1000-1200F closed arc 3) 150F hood
10) Glass Manufacturing	1) Regenerative tank furnace 2) Weight hoppers and mixers	1) Baghouse, scrubber precipitator 2) Same as 1	1) Direct tap 2) Canopy	1) Fan capacity 2) 200 fpm/ft^2	1) 600-850F furnace 2) 100F mixers
11) Grey Iron Foundries	1) Cupola 2) Electric arc furnace 3) Core oven 4) Shakeout	1) Afterburner-baghouse for closed cap, Afterburner-precipitator for closed cap, scrubber 2) Baghouse, scrubber precipitator 3) Afterburner 4) Baghouse	1) Direct tap 2) Direct tap, full/side draft hood 3) Direct tap 4) Full/side draft hood	1) Tuyere air + infil. door air + afterburner second air 2) 2000 fpm/ft^2 hood 3) Fan capacity 4) 200-500 cfm/ft^2 hood	1) 1200-2200F 2) ~2500F direct tap ~400F hood 3) 150F 4) ~150F

Table 2-1 INDUSTRY POLLUTANT SOURCES AND TYPICAL CONTROL DEVICES (cont'd)

INDUSTRY	SOURCE	CONTROL SYSTEM	CAPTURE DEVICE	TYPICAL GAS FLOW DESIGN RATE	TYPICAL GAS TEMPERATURE
12) Iron & Steel (Sintering)	1) Sinter machine a) Sinter bed b) Ignition fce. c) Wind boxes 2) a) Sinter crusher b) Conveyors c) Feeders	1) Precipitator, baghouse, scrubber 2) Baghouse, scrubber	1) Down draft hood 2) Canopy hood	1) Based on bed size 2) 250 fpm hood face	1) 150-400F sinter machine 2) 70F conveyors
13) Kraft Recovery Furnaces	1) Recovery furnace and direct contact evaporator	1) Precipitator, scrubber	1) Direct tap	1) Primary and secondary air supply capacity	1) 350F
14) Lime Kilns	1) Vertical kilns 2) Rotary sludge kiln	1) Baghouse, scrubber, precipitator 2) Scrubber, precipitator	1) Direct tap 2) Direct tap	1) Combustion air rate 2) Combustion air rate	1) 200-1200F 2) 200-1200F
15) Municipal Incinerator	1) Incinerator	1) Scrubber, precipitator, baghouse, afterburner	1) Direct tap	1) Combustion air fan capacity where applicable	1) 500-700F
16) Petroleum Catalytic Cracking	1) Catalyst regenerator	1) Precipitator, (boiler)-precipitator, scrubber	1) Direct tap a) High pressure b) Low pressure	1) Regeneration air rate + boiler combustion air	1) 1100F regenerator, 500F from boiler

Table 2-1 INDUSTRY POLLUTANT SOURCES AND TYPICAL CONTROL DEVICES (cont'd)

INDUSTRY	SOURCE	CONTROL SYSTEM	CAPTURE DEVICE	TYPICAL GAS FLOW DESIGN RATE	TYPICAL GAS TEMPERATURE
17) Phosphate Rock Crushing	1) Crusher & screens	1) Baghouse, scrubber, precipitator	1) Canopy hood	1) 350 cfm/ft belt width at speeds ~200 fpm 500 cfm/ft belt width at speeds ~2[illegible] fpm	1) 70F hoods
	2) Conveyor	2) Same as 1	2) Same as 1	2) 100 cfm/ft of casing cross-section (elevator) 50 cfm/ft of screen area	2) Same as 1
	3) Elevators	3) Same as 1	3) Same as 1	3) Combustion air rate	3) Same as 1
	4) Fluidized bed calciner	4) Same as 1	4) Same as 1	4) Blower rate	4) 600-1500F calciner
18) Polyvinyl Chloride Production	1) Process equipment vents	1) Adsorbers, afterburners, precipitators	1) Direct tap	1) Process gas stream rate	1) -15 to 130F
19) Pulp and Paper	1) Fluidized bed reactor	1) Scrubber	1) Direct tap	1) Combustion air rate	1) 600-1500F

Table 2-1 INDUSTRY POLLUTANT SOURCES AND TYPICAL CONTROL DEVICES (cont'd)

INDUSTRY	SOURCE	CONTROL SYSTEM	CAPTURE DEVICE	TYPICAL GAS FLOW DESIGN RATE	TYPICAL GAS TEMPERATURE
20) Secondary Aluminum	1) Reverbatory furnace	1) Scrubber (low energy) + baghouse, precipitator	1) Canopy hood (hearths), direct tap	1) Max. plume vol. + 20% (hearths)	1) 1600F fluxing, 600F holding hearth
	2) El. induction furnace	2) Same as 1	2) Same as 1	2) Infiltrated air	2) Based on type capture
	3) Crucible furnace	3) Same as 1	3) Same as 1	3) Same as 2	3) Same as 2
	4) Chlorinating station	4) Same as 1	4) Same as 1	4) Same as 2	4) Same as 2
	5) Dross processing	5) Same as 1	5) Same as 1	5) Same as 2	5) Same as 2
	6) Sweating furnace	6) Same as 1	6) Same as 1	6) Same as 2	6) Same as 2
21) Secondary Copper Smelters	1) Reverbatory furnace	1) Baghouse, scrubber precipitator	1) Direct tap, canopy hood, full hood	1) 200 fpm/ft^2 canopy hood	1) 2500F direct tap
	2) Crucible furnace	2) Same as 1	2) Same as 1	2) Max. plume vol. + 20%	2) Based on type capture
	3) Cupola & blast furnaces	3) Same as 1	3) Same as 1	3) 1800 fpm infiltrated air (full hood)	3) Same as 2
	4) Converters	4) Same as 1	4) Same as 1	4) Based on type capture	4) Same as 2
	5) El. induction furnaces	5) Same as 1	5) Same as 1	5) Same as 4	5) Same as 2
22) Sewage Sludge Incinerators	1) Multiple hearth incinerator	1) Scrubber	1) Direct tap	1) Combustion air blower capacity	1) 600 to 1500F
	2) Fluidized bed incinerator	2) Same as 1	2) Same as 1	2) Same as 1	2) Same as 1
23) Surface Coatings- Spray Booths	1) Spray booth	1) Adsorber	1) Canopy hood	1) 150 fpm/ft^2 hood, 100 fpm booth face velocity	1) 70F

Table 2-1 INDUSTRY POLLUTANT SOURCES AND TYPICAL CONTROL DEVICES (cont'd)

INDUSTRY	SOURCE	CONTROL SYSTEM	CAPTURE DEVICE	TYPICAL GAS FLOW DESIGN RATE	TYPICAL GAS TEMPERATURE
24) Portland Cement	1) Rotary kiln a) Wet b) Dry	1) Precipitators, baghouses	1) Direct tap	1) Combustion air rate where applicable	1) 150-850F kilns
	2) Crushers and conveyors	2) Baghouses	2) Canopy hoods	2) 250 fpm hood face	2) 70F crushers & conveyors
	3) Dryers	3) Precipitators, baghouses	3) Direct tap	3) Same as 1	3) 200F dryers
25) Basic Oxygen Furnaces	1) Basic oxygen furnace	1) Precipitator, scrubber, baghouse	1) Full-canopy hood	1) Function of lance rate and hood design - up to 1,000,000 acfm	1) 3500-4000F
	2) Charging hood	2) Same as 1	2) Canopy hood	2) 300 fpm hood face	2) 150-400F
26) Electric Arc Furnaces	1) Arc furnace	1) Baghouse, scrubber, precipitator	1) Direct tap, full/ side draft hood	1) Function of lance rate and hood design - up to 200,000 acfm	1) 3500F (direct tap)
	2) Charging and tapping	2) Same as 1	2) Canopy hood	2) 250 fpm hood face	2) 150F (canopy)
27) Phosphate Fertilizer	1) Digester vent air	1) Scrubber, baghouse	1) Hood	1) Process stream rate	1) 150F
	2) Filters	2) Same as 1	2) Same as 1	2) Same as 1	2) Same as 1
	3) Sumps	3) Same as 1	3) Same as 1	3) Same as 1	3) Same as 1

Table 2-2. DESIGN PARAMETERS FOR RESPECTIVE INDUSTRIES FOR HIGH EFFICIENCY PERFORMANCE*

Industry	Fabric Filter Air-to-Cloth Ratio			Venturi Scrubber	Precipitator
	Reverse Air	Pulse Jet	Mechanical Shaker	In. of Water	Drift Vel Ft/sec
Basic oxygen furnaces	1.5-2.0	6-8	2.5-3.0	40-60	.15-.25
Brick manufacturing	1.5-2.0	9-10	2.5-3.2	35	
Castable refractories	1.5-2.0	8-10	2.5-3.0		
Clay refractories	1.5-2.0	8-10	2.5-3.2	11	
Coal fired boilers				15	.22-.35
Conical incinerators					
Cotton ginning					
Detergent manufacturing	1.2-1.5	5-6	2.0-2.5	10-40	
Electric arc furnaces	1.5-2.0	6-8	2.5-3.0		.12-.16
Feed mills		10-15	3.5-5.0		
Ferroalloy plants	2.0	9	2.0	40-60-80	
Glass manufacturing	1.5			65	.14
Grey iron foundries	1.5-2.0	7-8	2.5-3.0	25-60	.1-.12
Iron and steel (sintering)	1.5-2.0	7-8	2.5-3.0		.2-.35
Kraft recovery furnaces				15-30	.2-.3
Lime kilns	1.5-2.0	8-9	2.5-3.0	12-40	.175-.25
Municipal incinerators					.2-.33
Petroleum catalytic cracking				40	.125-.175
Phosphate fertilizer	1.8-2.0	8-9	3.0-3.5	15-30	
Phosphate rock crushing		5-10	3.0-3.5	10-20	.35
Polyvinyl chloride production		7			
Portland cement	1.2-1.5	7-10	2.0-3.0		.2-.3
Pulp and paper (fluidized bed reactor)					
Secondary aluminum smelters		6-8	2.0	30	
Secondary copper smelters		6-8			.12-.14
Sewage sludge incinerators					
Surface coatings - spray booth					

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* High Efficiency - A sufficiently low grain loading to expect a clear stack.

Table 2-3 EFFICIENCY OF CARBON ADSORPTION AND LEL'S FOR COMMON POLLUTANTS

Pollutant	Lower explosive limit (percent by volume in air)	Carbon adsorption efficiency * (percent)
Acetone	2.15	8
Benzene	1.4	6
n-Butyl acetate	1.7	8
n-Butyl alcohol	1.7	8
Carbon tetrachloride	n	10
Chloroform	n	10
Cyclohexane	1.31	6
Ethyl acetate	2.2	8
Ethyl alcohol	3.3	8
Heptane	1	6
Hexane	1.3	6
Isobutyl alcohol	1.68	8
Isopropyl acetate	2.18	8
Isopropyl alcohol	2.5	8
Methyl acetate	4.1	7
Methyl alcohol	6.0	7
Methylene chloride	n	10
Methyl ethyl ketone	1.81	8
Methyl isobutyl ketone	1.4	7
Perchlorethylene	n	20
Toluene	1.27	7
Trichlorethylene	n	15
Trichloro trifluoroethane	n	8
V M & P Naptha	0.81	7
Xylene	1.0	10

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[*] Efficiencies are based on 200 cfm of 100F solvent-laden air, with no other impurities per hundred pounds of carbon per hour. Solvent recovery is 90-95%. Concentrations of solvent will alter efficiencies somewhat, but for estimating purposes those figures are satisfactory for 25 ppm and greater. See Section 4.5 for the use of this table. Source: Hoyt Manufacturing.

the 27 industries. Additional information on these industries may be obtained from these sources.

2.7 FACTORS AFFECTING RETROFIT COSTS

The cost of retrofitting an existing facility to include a pollution control system will usually cost more than the installation in a new facility. The increases in costs can be as high as 10 times the normal installation costs depending on the degree of plant modifications. It is difficult to accurately assess the increased costs for retrofitting without the plans and specifications of the particular plant and process being retrofitted. Some of the factors that attribute to the additional costs, however, are discussed as follows:

Plant age - Installation may require structural modifications to plant and process alterations.

Available space - May require extensive steel support construction and site preparation. Existing equipment may require removal and relocation. New equipment may require custom design to meet space allocations.

Utilities - Electrical, water supply, and waste removal and disposal facilities may require expansion.

Production Shut-down- Loss of Production during retrofit must be included in overall costs.

Labor - If retrofitting is accomplished during normal plant operations, installation time and labor hours will be increased. If installation occurs during off-hours, overtime wages may be necessary.

Engineering-Increased engineering costs to integrate control system into existing process.

SECTION 3

PROCEDURE FOR ESTIMATING COSTS

3.1 GENERAL

The cost curves presented in Section 4 represent the equipment costs for the various control devices and auxiliary equipment, together with the estimated installation and annual operating and maintenance costs for systems using these components. Installation costs for the equipment will depend on such factors as: physical location of the equipment within the plant, degree of assembly, availability of local erectors, wage rate and overtime requirements, availability of utilities, equipment transportation and difficulty of loading/unloading, and complexity of instrumentation and control. Turnkey cost estimates by most suppliers also include engineering and contingency costs. Engineering is generally estimated at 10 percent of the total equipment and installation cost. This includes start-up and performance testing besides the normal system design engineering. Contingencies are also included in the cost estimates. These contingencies cover unexpected costs due to inflation, union slow-downs and strikes, delays in receipt of materials, start-up and guarantee testing problems, subcontractor price adjustments, and other unforeseen problems. Contingency costs are generally estimated at 10 percent of the total costs. The capital costs for a control system are therefore itemized as follows.

1) Equipment costs (control device + auxiliaries) = $________

2) Tax and freight @7% of 1) * = $________

3) Installation costs (Table 4-12) = $________

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* Taxes range from 3-6%. Freight ranges from 1-5%. The 7% figure assumes 4% and 3% respectively.

4) Subtotal (1 + 2 + 3) = $_ _ _ _ _ _ _ _

5) Engineering @ 10% of 4)[*] = $__________

6) Subtotal (4 + 5) = $_ _ _ _ _ _ _ _

7) Contingencies @ 10% of 6)[**] = $__________

8) Total capital costs (6 + 7) = $_ _ _ _ _ _ _ _

For certain items, such as cooling towers, tall stacks, and refractory, installed prices are given in Section 4. The cost of such equipment, then, is not included in Line 1 above, rather these costs are added to Line 8 to arrive at the total capital cost for the system.

Operating and maintenance curves in Section 4 are based on the average costs for complete systems. Some costs may be higher or lower depending on the type of maintenance, system efficiency, labor and material rates, the number of hours operated per year, utility rates, and geographical location. Some plants within the same geographical location will pay lower power or utility rates than others due to the plant's total rate of consumption.

The use of the tables and curves in Section 4 to determine the capital, operating, and maintenance costs of the five control systems is discussed in Section 3.3 with a typical example of the procedures to be followed. Section 3.2 illustrates the use of life-cycle cost analysis. Appendix E provides factors for converting English units of measurement to the International System of Units (SI).

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[*] Engineering may range from 5-10%.

[**] Contingencies may exceed 20% for retrofits, repairs, or alterations.

3.2 COST COMPARISON METHODOLOGIES

To adequately compare the costs of alternative air pollution control systems, one needs a procedure for combining the aggregate effects of first cost, operating cost, maintenance cost, and other costs or economic benefits that may arise from owning and operating the system. The procedure to be presented here is known as life-cycle cost analysis.

Life-cycle costing may involve either of two techniques: the Present Worth method and the Uniform Annual Equivalent method. The Present Worth (PW) technique provides a means of calculating a single lump sum that at the present time would be equivalent to all present and future cash flows. If the PW's for all alternatives are calculated, then the one alternative having the lowest PW would be the most desirable from an owning and operating cost standpoint. The Uniform Annual Equivalent (UAE) technique provides a means of calculating an annual payment that would be equivalent to all present and future cash flows. The alternative having the lowest UAE would be the most desirable from an owning and operating cost standpoint. Both methods are valid approaches to life-cycle costing; the use of the one or the other depends on the user's individual preferences, and both will be described here.

The PW and UAE techniques incorporate the time value of money to calculate the equivalent value at present time of some future cash flow. Money has time value because a dollar now can be invested to yield more than a dollar at some future date - just as a bank pays interest on a personal savings account. The general formula for the PW of a future cash outlay, F, taking place n periods from the present, given a discount rate, i, is:

Eq(3-1) $$PW = \frac{F}{(1+i)^n}.$$

The PW of a uniform annual payment, A, is:

Eq(3-2)
$$PW = A\left[\frac{(1+i)^n - 1}{i\,(1+i)^n}\right].$$
(n is the number of periods over which the annual payment takes effect)

The UAE of a PW is:

Eq(3-3)
$$UAE = PW\left[\frac{i\,(1+i)^n}{(1+i)^n - 1}\right]$$

Hence, for example:

$$\$1{,}627.50 = \$10{,}000\left[\frac{(.1)(1.1)^{10}}{(1.1)^{10}-1}\right].$$

These formulas are provided for the reader's reference. However, in general practice one makes use of tables, which are given in Appendix A, Compound Interest Factors. The use of these tables is now described. In Equation 3-1 above, the compound interest factor is known as the single payment present worth factor and is typically denoted by (P/F, n) which reads "present worth from future amount". The F symbolizes a single payment at some future date, n periods from the present. In Equation 3-2, the compound interest factor is known as the uniform series present worth factor and is typically denoted by (P/A, n), which reads "present worth from an annuity". The A symbolizes a uniform series of annual payments commencing at the end of year one and stopping at the end of year n. In Equation 3-3, the compound interest factor is known as the capital recovery factor, and is typically denoted as (A/P, n), which reads "the annuity from the present amount", which extends for n periods. Using the capital recovery factor, one can compute the UAE from the PW. In the tables just mentioned, these factors are provided. As an example of their use, consider the calculation of PW for an initial payment of \$3000, an annual payment of \$1000 for 10 years, and a lump sum payment of \$1379 at the end of year 5:

$$PW = \$3000 + 1000\,(P/A,\ 10) + \$1379\,(P/F,\ 5)$$

To clarify, the \$3000 has no factor since it is already in the present; the \$1000 occurs each year for ten years (an annuity); in the fifth year there is an additional single payment expense of \$1379. Refering to Table A-9, the factors are found to be, for a 10% discount rate:

$$PW = \$3000 + \$1000\ (6.144) + \$1379\ (0.6209)$$
$$= \$10{,}000.$$

Additionally, one can compute that the

$$UAE = PW\ (A/P,10)$$
$$= \$10{,}000\ (0.16275)$$
$$= \$1627.5$$

There is yet one final topic that needs to be discussed and that is the selection of the discount rate. In its most limited sense, interest is the money paid for the use of borrowed capital. But in life-cycle cost analysis, a broader view is required; interest is the cost of employing capital for air pollution control. If in fact the capital needed for owning and operating air pollution control equipment comes from direct loans, then the discount rate used in the PW and UAE calculations is equal to the interest rate of the loans. A similar statement can be made for bond issues. The discount rate for government investments is the interest rate the treasury must pay to borrow money. A more complicated situation arises however when the firm does not borrow, but instead uses equity funds. In this case, the discount rate is the cost of employing equity, which is the expected rate of return on investments that the firm can make. Higher discount rates tend to favour lower first costs, since the high rate of discounting considerably reduces the present worth of future cash outlays. The selection of the discount rate should be given serious thought, because the ranking of investment alternatives can vary according to the level of the discount rate.

Example of the use of life-cycle costing is given in Section 3.3. More extended discussion of cost analysis may be found in the book, Principles of Engineering Economy by Grant and Ireson, the Ronald Press Company, New York, New York, 1970. The reader is encouraged to study this text, as there are many important topics and caveats that could not be covered in this brief space. Some special concerns include: proper handling of depreciation and tax effects, equipment replacement, lease or buy decision, unequal equipment lives, determining the discount rate, calculating utility costs, etc. However these subjects are principally the internal concern of the purchaser of abatement equipment.

3.3 EXAMPLE CASE STUDY

For purposes of illustration of the use of the manual, a case study on rotary lime kiln air pollution control is presented here. Since this manual provides very little guidance regarding the design of air pollution control systems, it is essential that the user have prepared in advance an engineering design for control of the pollutant source. Care should be taken in performing the design because a poor design is likely to result in unrealistic costs. There may be many system configurations that will satisfy the technical requirements, but only one or two will cost the least. In the example presented here, the engineering design is intended to demonstrate the use of the manual and is simplified in the interest of clarity and brevity. Hence the design may not be optimal. The reader should however, concentrate on understanding how the manual is used. Engineering design techniques may be found in EPA Pub. AP-40, Air Pollution Engineering Manual. (see Appendix C, No. 88)

Lime (CaO or CaO·MgO) is the product of the calcination of limestone ($CaCO_3$ or $CaCO_3 \cdot MgCO_3$). Lime manufacturing involves several sources of pollutants. The sources include:

a) Quarrying - stripping, drilling, blasting, loading, and hauling.

b) Stone processing - crushing, pulverizing, screening, and conveying.

c) Limestone calcining (kilns).

d) Lime hydration, drying, and bagging.

e) Fugitive dust-roads, stockpiles, transportation, etc.

This section is concerned solely with rotary lime kiln operations. Kilns are basically of two types: vertical and rotary. Rotary kilns are used by the majority (80-90%) of lime plants and they represent the largest single source of pollutants in the lime industry. The pollutants are predominately particulate matter. Broadly speaking, about 30% of the dust from rotary kilns is less than 10μ and the mean size is 30μ. The exhaust temperature from rotary kilns depends on the length of the kiln and other process variables. Lime kiln exhaust gas is usually cleaned with venturi scrubbers or fabric filters, although electrostatic precipitators may also be used. This case study will show cost estimation for all three methods. The following conditions are assumed:

- A typical 250 TPD rotary kiln to be controlled at 1000 ft elevation.
- Required control efficiency of 99+%.
- Exhaust gas from kiln: 30,000 SCFM or 88,300 ACFM @ 1100F.
- Control device to be located 200' from source.
- Direct tap of exhaust from kiln.
- Duct velocity = 4000 fpm to prevent fallout
- Surrounding terrain does not impose unusual constraints on system design and stack height (50').

OUTLINE OF ENGINEERING CALCULATIONS

Case A - fabric filter

Establish overall engineering design as follows:

a. Use polyester (275F) or glass bags (550F).

b. A/C ratio = 2 for glass bags.
= 3 for polyester bags.

c. Suction baghouse:
- reverse air, insulated for glass bags
- mechanical shaker, insulated for polyester bags

d. Radiant coolers next to source.

e. Mechanical cyclone just prior to baghouse.

f. Dilution air port provided for temperature modulation.

g. By-pass damper omitted.

Figure 3-1 shows the system layout for a fabric filter operation. The following discussion outlines how the design parameters are obtained for each stage along the system.

Stage 1: Direct exhaust from kiln, determine carbon steel elbow duct size:

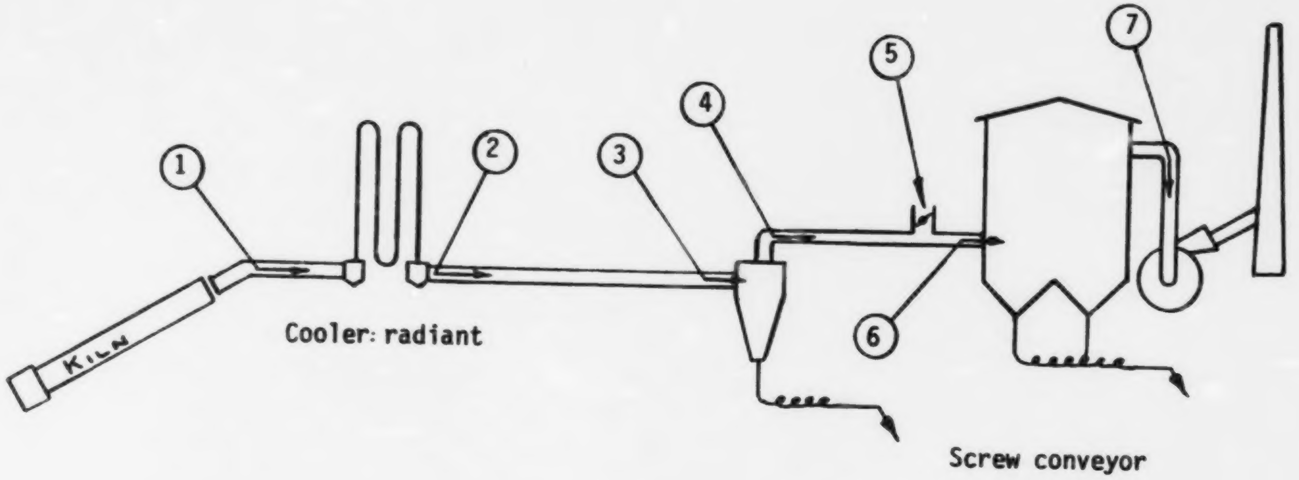
$$\frac{88300\text{ ACFM}}{4000\text{ fpm}} = 22.1\text{ Ft}^2$$

Hence, 64" duct (22.3 ft^2) may be used, giving:

$$\frac{88300\text{ ACFM}}{22.3\text{ ft}^2} = 3960\text{ fpm}$$

Stage 2. a. Assume no temperature drop from kiln outlet to inlet of radiant cooler. Estimate that about 600 F temperature is required out of the cooler. Try initial 5000 fpm through two 18" U tubes in series. Thus need

$$\frac{88300\text{ ACFM}}{1.767\text{ ft}^2/_{\text{tube}} \times 5000\text{ fpm}} = 10\text{ pairs of tubes in parallel}$$


KILN
Cooler: radiant
Screw conveyor
1
2
3
4
5
6
7

DESIGN PARAMETERS	1	2	3	4	5	6	7
SCFM	30,000	30,000	30,000	30,000	38,600[b]	30,000[a] 68,600[b]	30,000[a] 68,600[b]
TEMPERATURE	1100 F	600 F	530 F	500 F	100 F[b]	500 F[a] 275 F[b]	500 F[a] 275 F[b]
ACFM	88,300	60,000	56,000	54,300	40,800[b]	54,300[a] 95,100[b]	54,300[a] 95,100[b]
DUCT DIAMETER	64"	50"	50"	50"	50"	Neglect	Neglect
STATIC PRES. (" WG)	Kiln Draft	-2.1"	-2.7"	-8.7"	-	-	-14.7"

a - glass bag
b - polyester bag

Figure 3-1 FABRIC FILTER SYSTEM DESIGN

From engineering calculations*for 40' high tubes, the temperature drop for two tubes in series is 500F. Thus exit temperature is 600F and gas volume is 60000 ACFM. Pressure drop is 2.1" W.G. Estimated length of cooler is 30 feet.

b. Determine carbon steel duct diameter

$$\frac{60000 \text{ ACFM}}{4000 \text{ fpm}} = 15 \text{ ft}^2$$

Hence 50" duct (13.6 ft^2) may be used, giving:

$$\frac{60000 \text{ ACFM}}{13.6 \text{ ft}^2} = 4400 \text{ fpm}$$

Stage 3. Cooling of gas will take place over 200-30 = 170 ft. of duct. Using engineering calculations, it is found that 600F gas through 170' of duct drops to about 530F. Therefore, the new ACFM is:

$$60000 \text{ ACFM} \times \frac{990 \text{ R}}{1060 \text{ R}} = 56000 \text{ ACFM}$$

Check duct velocity:

$$\frac{56000 \text{ ACFM}}{13.6 \text{ ft}^2} = 4100 \text{ fpm}$$

Hence duct size remains at 50" throughout. Two expansion joints will be required, one 50", the other 64". Pressure drop through duct is about 1/3" per 100 ft or .6" W.G.

---

* Heat transfer calculation methods may be found in the EPA publication AP-40, See Appendix C, reference 88.

Stage 4. Select two mechanical collectors in parallel to handle 28000 ACFM each. For 6" pressure loss, the inlet area is 8.5 ft^2 and the critical partical size is 24 microns. Temperature drop will be about 30F, thus new gas volume is:

$$56000 \text{ ACFM} \times \frac{960 \text{ R}}{990 \text{ R}} = 54{,}300 \text{ ACFM}$$

Stage 5. Dilution air port is provided for baghouse for modulation of gas temperature. For glass bags, no dilution air will generally be required. For polyester bags, dilution air is estimated as follows (neglecting the difference in heat capacities):

$$(30{,}000 \text{ SCFM})(500\text{F}) + \text{D}\ (100\text{F}) = (30000+\text{D})(275\text{F})$$

$$\text{D} = 38{,}600 \text{ SCFM}$$

Stage 6. Hence total gas volume is 68,600 SCFM or 95100 ACFM @ 275F for polyester bags, and is 54300 ACFM @ 500F for glass bags.

The baghouse is sized as follows:

a. For glass bags:

$$\frac{54300 \text{ ACFM}}{2.0 \text{ A/C}} = 27150 \text{ ft}^2 \text{ net cloth area.}$$

b. For polyester bags:

$$\frac{95100 \text{ ACFM}}{3.0 \text{ A/C}} = 31700 \text{ ft}^2 \text{ net cloth area}$$

Baghouses are nominally sized for 6" W.G. Neglect temperature drop through the baghouse.

Stage 7. Total pressure drop across system is:

Radiant cooler -	2.1" W.G.
Ductwork	.6"
Mechanical collector	6.0"
Baghouse	6.0"
	14.7" W.G.

Size fans for 54,300 ACFM and 95,100 ACFM for glass and polyester bags respectively. Select 50' high stacks of 50" and 66" respectively. Fifty feet of 9" diameter screw conveyor will be required.

Case B - Electrostatic Precipitator

Establish overall engineering design as follows:

a. Drift velocity = .25 fps.

b. Insulated precipitator

c. Inlet gas temperature of 700F for good resistivity

d. Spray chamber next to source

Figure 3-2 shows the system layout for an electrostatic precipitator operation. The following discussion outlines how the design parameters are obtained for each stage along the system.

Stage 1. Same as for Case A, Fabric Filter.

Stage 2. Estimate spray chamber outlet temperature of 800F. Water required is about 15 gpm. Chamber length is about 35 feet. New gas volume will be:

$$88{,}300 \text{ ACFM} \times \frac{1260 \text{ R}}{1560 \text{ R}} = 71300 \text{ ACFM}$$

Calculate duct diameter:

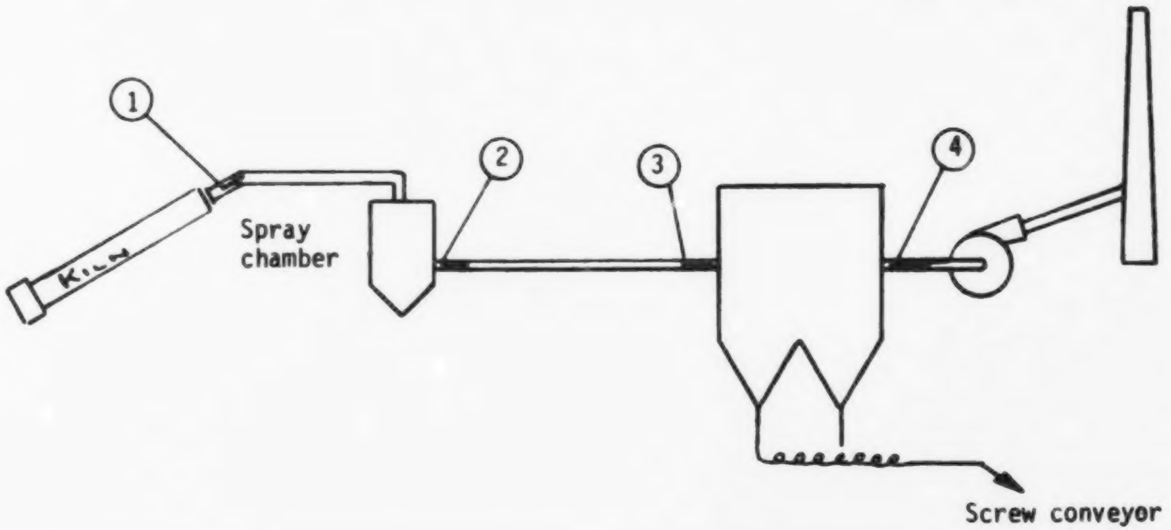
$$\frac{71{,}300 \text{ ACFM}}{4000 \text{ fpm}} = 17.8 \text{ ft}^2$$

Hence 55" duct (16.5 ft^2) may be used, giving:

$$\frac{71{,}300 \text{ ACFM}}{16.5 \text{ ft}^2} = 4300 \text{ fpm}$$

Stage 3. a. Cooling through duct will be about 110F (for 200-35=165 ft). Hence final temperature is 690F and new gas volume is:

$$71300 \text{ ACFM} \times \frac{1150 \text{ R}}{1260 \text{ R}} = 65000 \text{ ACFM}$$


1
Kiln
Spray chamber
2
3
4
Screw conveyor

DESIGN PARAMETER	1	2	3	4
SCFM	30,000	30,000	30,000	30,000
TEMPERATURE	1100 F	800 F	690 F	690 F
ACFM	88,300	71,300	65,000	65,000
DUCT DIAMETER	64"	55"	55"	Neglect
STATIC PRES. (" WG)	Kiln Draft		-1.0"	-1.5"

Figure 3-2 ELECTROSTATIC PRECIPITATOR SYSTEM DESIGN

Check duct velocity:

$$\frac{65{,}000\ \text{ACFM}}{16.5\ \text{ft}^2} = 3940\ \text{fpm (OK)}.$$

Two expansion joints will be needed as for baghouses.

b. Size precipitator as follows:

$A = -65{,}000\ \text{ACFM}\ \ln(1-.993)/(0.25\ \text{fps} \times 60\ \text{s/min})$

$A = 21500\ \text{ft}^2$

Stage 4. Total pressure drop across system is:

Spray chamber and duct - 1.0" W.G.
Precipitator - .5" W.G.
Total 1.5" W.G.

Size fan for 65,000 ACFM. Select a 50' high stack 55" diameter.

Fifty feet of screw conveyor 9" in diameter will be required.

Calculate KW of system for operating cost:

15 gpm pump has ∿5 HP motor =	3.7 KW
Screw conveyor has ∿5 HP motor =	3.7 KW
Fan has ∿10 HP motor =	7.5 KW
Precipitator requires	78.3 KW
Total	93.2 KW
or	1.43 KW per 1000 ACFM

Case C - Venturi Scrubber

Establish overall engineering design as follows:

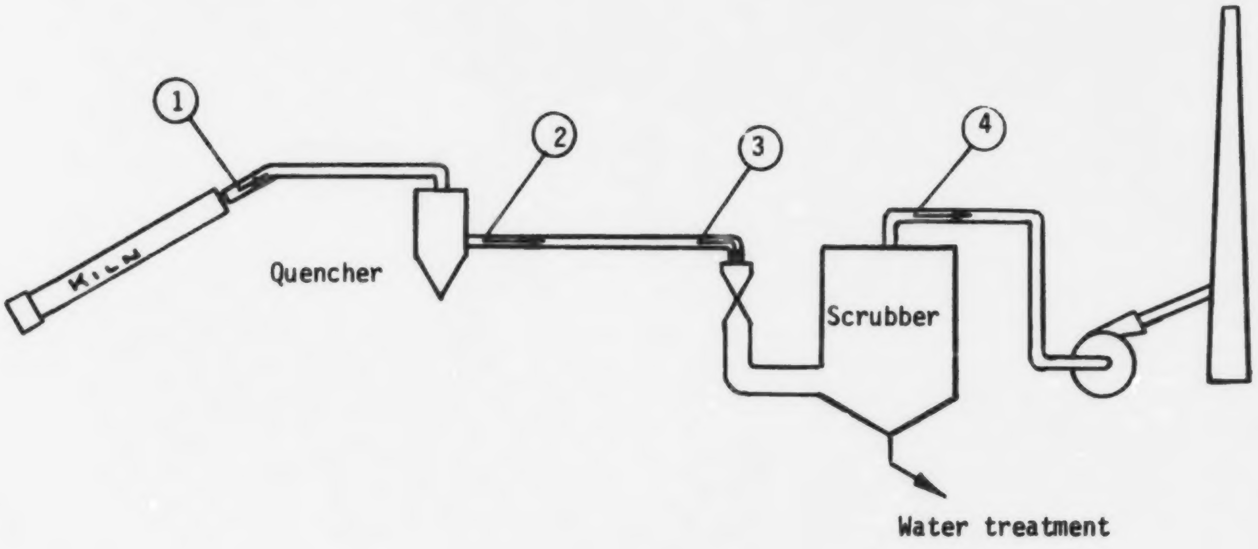
a. Venturi scrubber pressure drop estimated at 15" W.G.

b. Carbon steel, unlined construction

c. Quencher next to source.

Figure 3-3 shows the system layout for a venturi scrubber operation. The following discussion outlines how the design parameters are obtained for each stage along the system.

Stage 1. Same as for Case A, Fabric Filter.



①
KILN
Quencher
②
③
④
Scrubber
Water treatment

DESIGN PARAMETER	1	2	3	4
SCFM	30,000	40,200	40,200	30,000
TEMPERATURE	1100 F	220 F	190 F	100 F
CFM	88,300	52,000	49,700	48,200
DUCT DIAMETER	64"	48"	48"	Neglect
STATIC PRES. (" WG)	Kiln Draft		-1"	-16"

Figure 3-3 VENTURI SCRUBBER SYSTEM DESIGN

Stage 2. a. Quencher is sized at about 60 gpm and 30' long to cool gas from 1100F to 220F. New gas volume is:

gas: $$88{,}300 \text{ ACFM} \times \frac{680 \text{ R}}{1560 \text{ R}} = 38{,}500 \text{ ACFM}$$

water vapor: $$60 \text{ gpm} \times 8.33 \text{ lb/gal} \times \frac{680 \text{ R}}{530 \text{ R}} \times 21.1 \text{ cu ft/lb} = 13500 \text{ ACFM}$$

total: $38{,}500 + 13500 = 52{,}000$ ACFM

b. Required duct size is:

$$\frac{52{,}000 \text{ ACFM}}{4{,}000 \text{ fpm}} = 13.0 \text{ ft}^2$$

Hence a 48" (12.57 ft^2) duct may be used giving:

$$\frac{52{,}000 \text{ ACFM}}{12.57 \text{ ft}^2} = 4140 \text{ fpm}$$

Stage 3. Through 170 ft of duct the gas temperature drops to about 190F, hence the new gas volume is:

$$52{,}000 \text{ ACFM} \times \frac{650 \text{ R}}{680 \text{ R}} = 49{,}700 \text{ ACFM.}$$

Check duct velocity:

$$\frac{49{,}700 \text{ ACFM}}{12.57 \text{ ft}^2} = 3950 \text{ fpm (OK).}$$

Stage 4. Scrubber is sized for 49,700 ACFM; and will be constructed of 3/16" steel to allow for erosion. Estimated gas exit temperature is 170F. Fan is sized for:

$$49{,}700 \text{ ACFM} \times \frac{630 \text{ R}}{650 \text{ R}} = 48{,}200 \text{ ACFM}$$

Select a 48" stack.

ESTIMATING PURCHASE PRICE OF CONTROL SYSTEMS

Case A - Fabric Filter

a.	(1) 64" carbon steel elbow, ¼" Thick (Figure 4-24) -		$ 1,800
b.	(20) branches of 18" carbon steel radiant cooler 40' high (Figure 4-31) -		62,000
c.	(170) feet of 50" carbon steel duct 3/16" thick (Figure 4-21) -		9,700
d.	(2) carbon steel, 10 Ga., mechanical collectors with inlet area = 8.5 ft^2 -		18,200
	Collector (Figure 4-35) -	$4100	
	Support (Figure 4-37) -	2600	
	3/16" Hopper (Figure 4-38)-	800	
	Scroll (Figure 4-39) -	1600	
	Total Each	$9100	
e.	(1) 3/16" transition to mechanical collector (Figure 4-24) -		600
	(2) expansion joints, one 50", one 64" (Figure 4-28)-		6,000
	Sub-Total		$ 98,300

Glass Bags

f.	(1) 50" carbon steel dilution air port, 3/16" thick (Figure 4-32)	5,000
g.	(1) 27,150 ft^2 net cloth area, continuous, reverse air, insulated baghouse (Figure 4-10) -	140,400
h.	Suction add-on (Figure 4-10) -	9,100
i.	(1 set) 27,150 X 1.17 = 31,765 sq ft gross area glass bags (Table 4-1) -	12,700
j.	(1) 54,300 ACFM backwardly curved Class IV fan at 14.7"WG actual (29" standard) (Figure 4-40) -	5,600
k.	(1) 1,800 RPM, 180 HP drip proof motor (Figure 4-41) -	$ 2,400
l.	(1) Magnetic starter with circuit breaker (Figure 4-41) -	1,400
m.	(1) 50" diameter, 50' high stack, 1/4" thick (Figure 4-48) -	4,400
n.	(50) feet of 9" screw conveyor (Figure 4-57)	3,400
	Sub-Total	$184,400

Polyester Bags

f.	(1) 66" carbon steel dilution air port, 1/4" thick (Figure 4-32) -	$ 6,800
g.	(1) 31,700 ft^2 net cloth area, continuous, mechanical shaker baghouse (Figure 4-9) -	100,900
h.	Suction add-or (Figure 4-9) -	8,900
i.	Insulation add-on (Figure 4-9) -	49,500
j.	(1) set 31,700 X 1.17 = 37,089 sq ft gross area Dacron bags (Table 4-1) -	11,100
k.	(1) 95,100 ACFM backwardly curved Class IV fan at 14.7" WG actual (29" standard) (Figure 4-40)-	9,000
l.	(1) 1,800 RPM, 300 HP, drip-proof motor (Figure 4-41)	4,400
m.	(1) magnetic starter with circuit breaker (Figure 4-41) -	3,000
n.	(1) 66" diameter, 50' high stack, 1/4" thick (Figure 4-48) -	5,200
o.	(50) feet of 9" screw conveyor (Figure 4-57)-	3,400
	Sub-Total	$202,200

Total capital and operating cost for the fabric filter system is summarized below, see Table 4-12 for installation and maintenance cost and Figure 4-60 for operating costs:

	Glass Bag	Polyester Bag
Equipment	$282,700	$300,500
Installation (75%)	212,000	225,400
Maintenance (2%)	4700/yr	6000/yr
Operating (8000 hrs)	14,400/yr	25,600/yr
Bags (life: 1.5; 2.0 yr)	8,500/yr	5,600/yr

Case B - Electrostatic Precipitator

a.	(1) 64" carbon steel elbow, 1/4" thick (Figure 4-24) -	$ 1,800
b.	(1) spray chamber @ 88,300 ACFM (Figure 4-29)-	55,000
c.	(165) feet of 55" carbon steel duct 3/16" thick (Figure 4-21) -	10,400
d.	(2) expansion joints, one 55" and one 64" (Figure 4-26) -	6,600
e.	(1) 21,500 ft^2 precipitator, insulated (Figure 4-1) -	206,700
f.	(1) 65,000 ACFM backwardly curved Class I fan at 1.5" WG actual (3.4" standard) (Figure 4-40)-	7,500
g.	(1) 600 RPM,45 BHP drip-proof motor (Figure 4-41)-	2,100
h.	(1) magnetic starter with circuit breaker (Figure 4-41)-	300
i.	(1) 55" diameter, 50' high stack, 1/4" thick (Figure 4-48) -	4,700
j.	(50) feet of 9" screw conveyor (Figure 4-57)-	3,400
	Total Equipment	$298,500
	Installation (75%)	223,900
	Maintenance (2%)	4,400/yr
	Operation (8000 Hrs) (See Figure 4-58)	14,400/yr

Case C - Venturi Scrubber

a.	(1) 64" carbon steel elbow, 1/4" thick (Figure 4-24) -	$ 1,800
b.	(1) quencher @ 88,300 ACFM (Figure 4-30) -	25,000
c.	(1) quencher pump for 60 gpm (Figure 4-53) -	700
d.	(170) feet of 48" carbon steel duct, 3/16" thick (Figure 4-21) -	9,300
e.	(2) expansion joints, one 48" and one 64" (Figure 4-26) -	6,000
f.	(1) 49,700 ACFM scrubber, 3/16" thick (Figure 4-2)-	22,000

g.	(1) 48,200 ACFM radial-tip fan at 16" WG actual (20" standard) (Figure 4-42) -	$ 8,000
h.	(1) 900 RPM, 225 HP drip-proof motor (Figure 4-41)-	6,000
i.	(1) magnetic starter with circuit breaker (Figure 4-41) -	2,000
j.	(1) 48' diameter, 50' high stack, 1/4" thick (Figure 4-48) -	4,400
	Total Equipment	$ 85,200
	Installation (140%)	119,300
	Maintenance (13%)	11,100/yr
	Operation (8000 Hrs) (See Figure 4-59)	36,000/yr

COST COMPARISON

Initial capital investments for the three alternative systems will be:

	Fabric Filter	Electrostatic Precipitator	Venturi Scrubber
Equipment	$282,700	$298,500	$85,200
Tax & Freight @ 7%	19,800	20,900	6,000
Installation	212,000	223,900	119,300
Sub Total	$514,500	$543,300	$210,500
Engineering @ 10%	51,400	54,300	21,000
Sub Total	$565,900	$597,600	$231,500
Contingencies @ 10%	56,600	59,800	23,200
Sub Total	$622,500	$657,400	$254,700

The calculation of Present Worth (PW) for a 10% discount rate is given below. The effect of income taxes on PW is not considered, although in practice one should consider tax effects, depending on tax advantages available to the firm.

Case A - Fabric Filter

Estimate equipment life of 20 years and glass bag life of 1.5 years. The calculation of Present Worth (PW) for a 10% discount factor is shown below. Annual bag cost is figured at \$12,700/1.5 = \$8500

PW = \$622,500 + \$4,700 (P/A,20) + \$14,400 (P/A,20) + \$8500 (P/A,20)
= \$622,500 + \$27,600 X 8.514
= \$857,500 ± \$171,000.

Case B - Electrostatic Precipitator

Estimate equipment life of 20 years.

PW = \$657,400 + \$4400 (P/A,20) + \$14,400 (P/A,20)
= \$657,400 + \$18,800 (8.514)
= \$817,500 ± \$163,000.

Case C - Venturi Scrubber

Estimate equipment life of 10 years.

PW = \$254,700 + \$11,000 (P/A, 20) + \$36,000 (P/A, 20) + \$254,700 (P/F,10)
= \$254,700 + \$47,000 (8.514) + \$254,700 (0.3855)
= \$753,000 ± \$151,000.

Because the equipment costs are accurate to ±20%, the overall installed equipment cost is also subject to the same accuracy. Hence the cost of the scrubber system could range from \$602,000 to \$904,000, but a nominal estimate would be \$753,000. The range for the precipitator system is \$654,000 to \$980,000 and the range for the fabric filter system is \$686,000 to \$1,028,000. The user of this manual should not determine what is the most economical system from these figures-rather the conclusion to be drawn is that a control system would cost something between the ranges indicated above. However, the designs presented here are not necessarily optimal, so this analysis should not be viewed as realistic from a design and cost standpoint, rather the reader should concentrate on understanding the use of the manual.

SECTION 4

CONTROL EQUIPMENT COSTS AND SELECTED DESIGN DATA

4.1 ELECTROSTATIC PRECIPITATORS

Prices for dry type (mechanical rapper or vibrator) precipitators are contained in Figure 4-1. These prices may also be used for rapper type, wet bottom precipitators. Prices are a function of net plate area, which can be calculated using the Deutsch equation:

(1) $\eta = 1 - e^{(-wA/Q)}$

or

(2) $A = -Q \ln (1-\eta)/w$

where η is efficiency

w is drift velocity, f/s

A is net plate area, ft^2

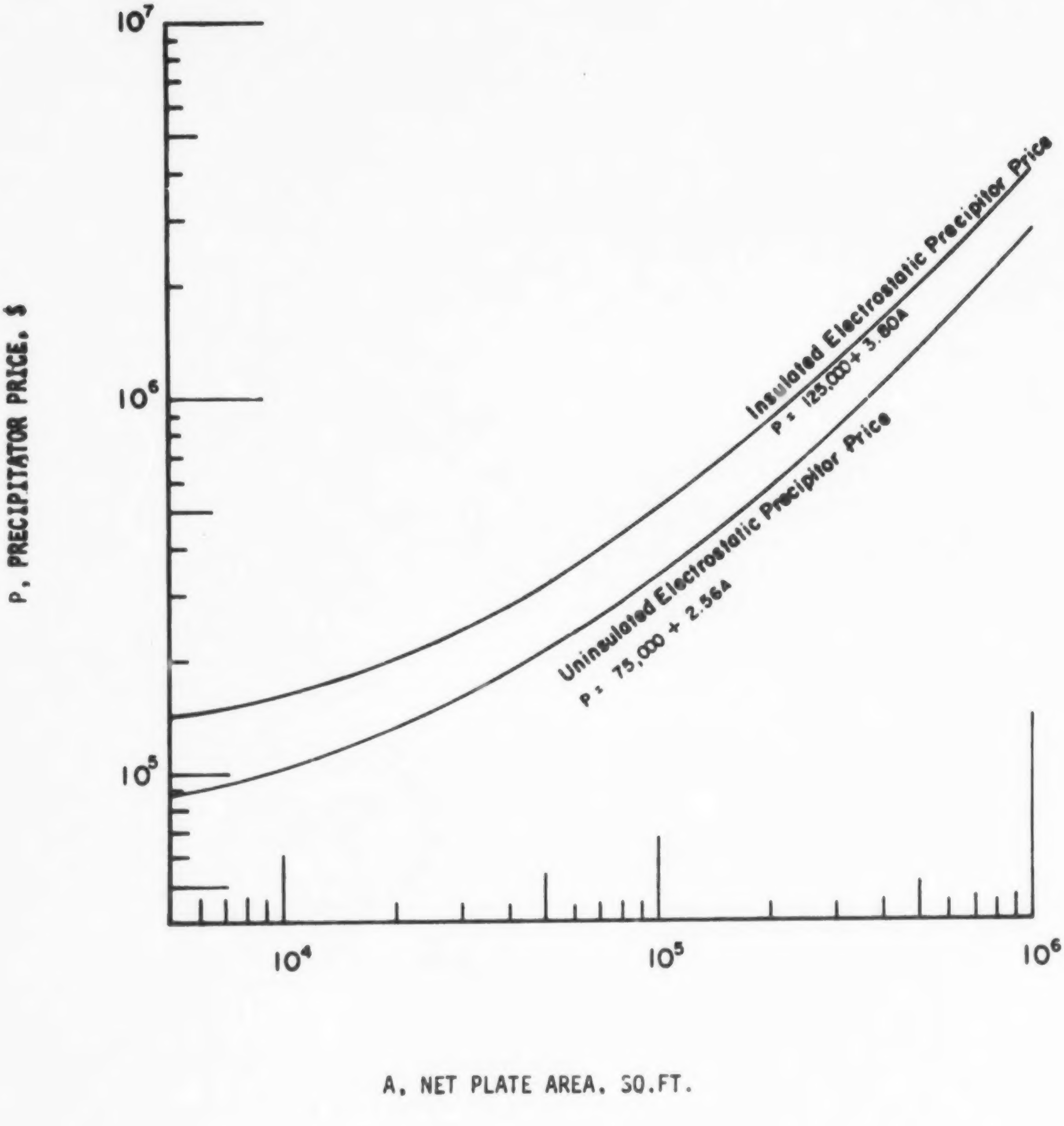
Q is flow rate, cfs

exp is e, the Naperian log base

For example, for gray iron foundries the drift velocity, w, is typically 0.12 f/s. If 99% cleaning efficiency is required on a flow rate of 10,000 cfm into the precipitator, the net plate area is calculated as follows:

$$A = (-10000 \text{ cfm} * \ln (1-.99))/(0.12 \text{ f/s} * 60 \text{ s/m})$$
$$= 6396 \text{ ft}^2$$

For the required plate area read the price for either the insulated or uninsulated precipitators, depending on design requirements.



DATA VALID FOR DECEMBER 1975

Figure 4-1 DRY TYPE ELECTROSTATIC PRECIPITATOR PURCHASE PRICES VS. PLATE AREA

4.2 VENTURI SCRUBBERS

Prices for venturi scrubbers are contained in Figures 4-2 through 4-6.

To price a scrubber using these curves, use the following steps.

A. Determine the gas volume entering the venturi section and read the price for a 1/8" thick carbon steel scrubber from Figure 4-2. For example, at 100,000 ACFM the price is approximately $34,000.

B. Determine the pressure drop across the scrubber required to obtain the desired efficiency (see Table 2-2) and find the required metal thickness for the design inlet volume from Figure 4-3. For 100,000 ACFM and 30", the required metal thickness is ¼" plate (always round up to the next standard plate thickness).

C. From Figure 4-4, find the price adjustment factor for the design inlet volume and the material thickness found in Step B. For 100,000 ACFM and ¼" plate, the factor is approximately 1.6. Thus, the carbon steel scrubber price is now $34,000 X 1.6 = $54,400.

D. If stainless steel construction, rubber or fiberglas lining, or variable venturi section is to be included, refer to Figure 4-2 and adjust price accordingly. For 304 stainless steel construction, the adjusted price would be $54,400 X 1.8 = $97,920. If rubber linings are required, refer to Figure 4-5 to determine total square footage.

E. If an internal gas cooler is to be used, determine the number of trays that can be fit into the separator (from separator height, Figure 4-5), and determine the diameter of each tray (from separator diameter, Figure 4-5). Read price for one tray from Figure 4-6. For 100,000 ACFM the separator diameter is approximately 13.5 ft. Thus the price for one tray is about $13,000.

NOTE: Radial tip fans are commonly used with scrubbers.

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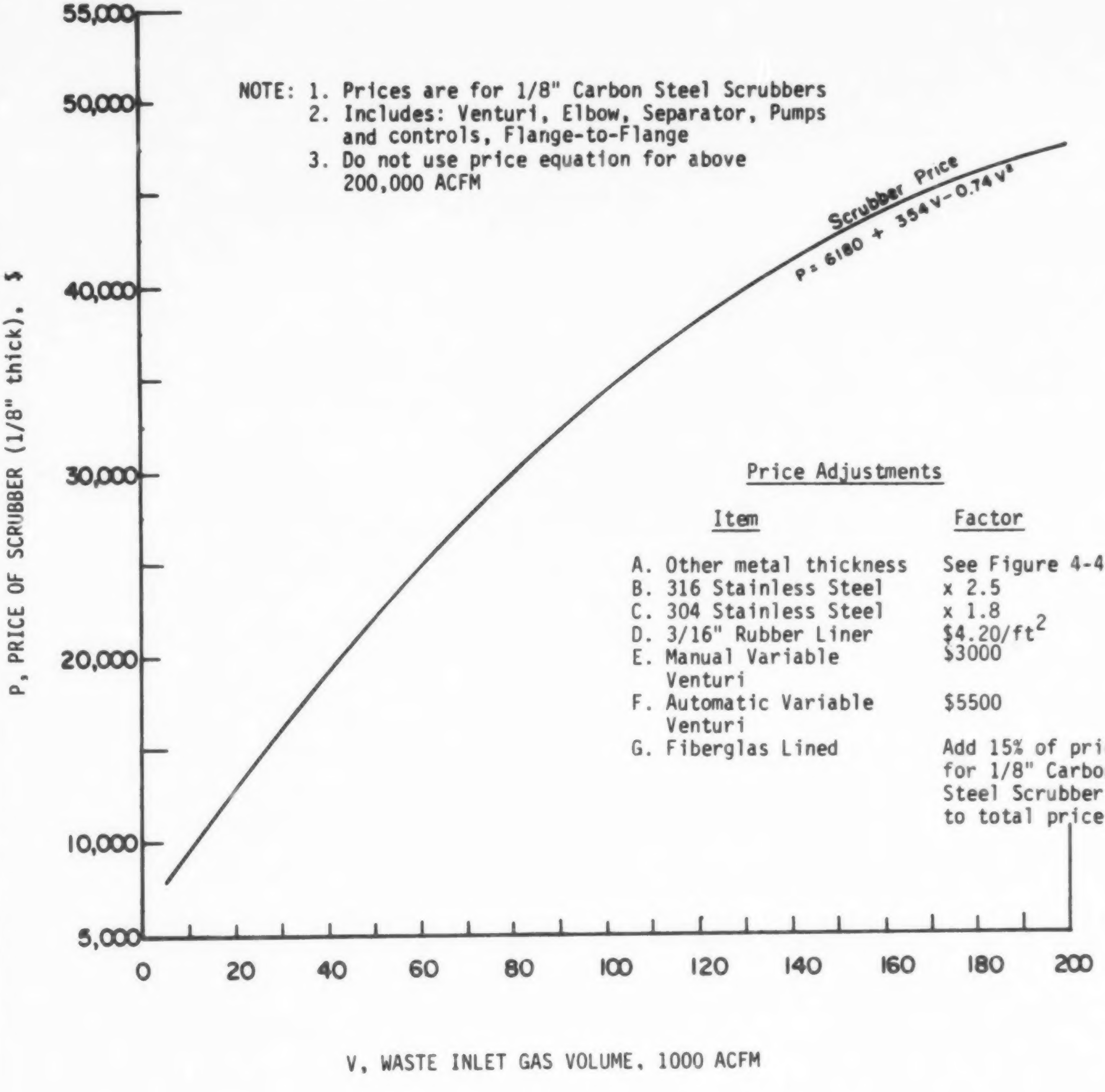


NOTE:
1. Prices are for 1/8" Carbon Steel Scrubbers
2. Includes: Venturi, Elbow, Separator, Pumps and controls, Flange-to-Flange
3. Do not use price equation for above 200,000 ACFM

Price Adjustments

Item	Factor
A. Other metal thickness	See Figure 4-4
B. 316 Stainless Steel	x 2.5
C. 304 Stainless Steel	x 1.8
D. 3/16" Rubber Liner	$4.20/ft^2
E. Manual Variable Venturi	$3000
F. Automatic Variable Venturi	$5500
G. Fiberglas Lined	Add 15% of price for 1/8" Carbon Steel Scrubber to total price

Figure 4-2 1/8" THICK CARBON STEEL FABRICATED SCRUBBER PRICE VS. VOLUME

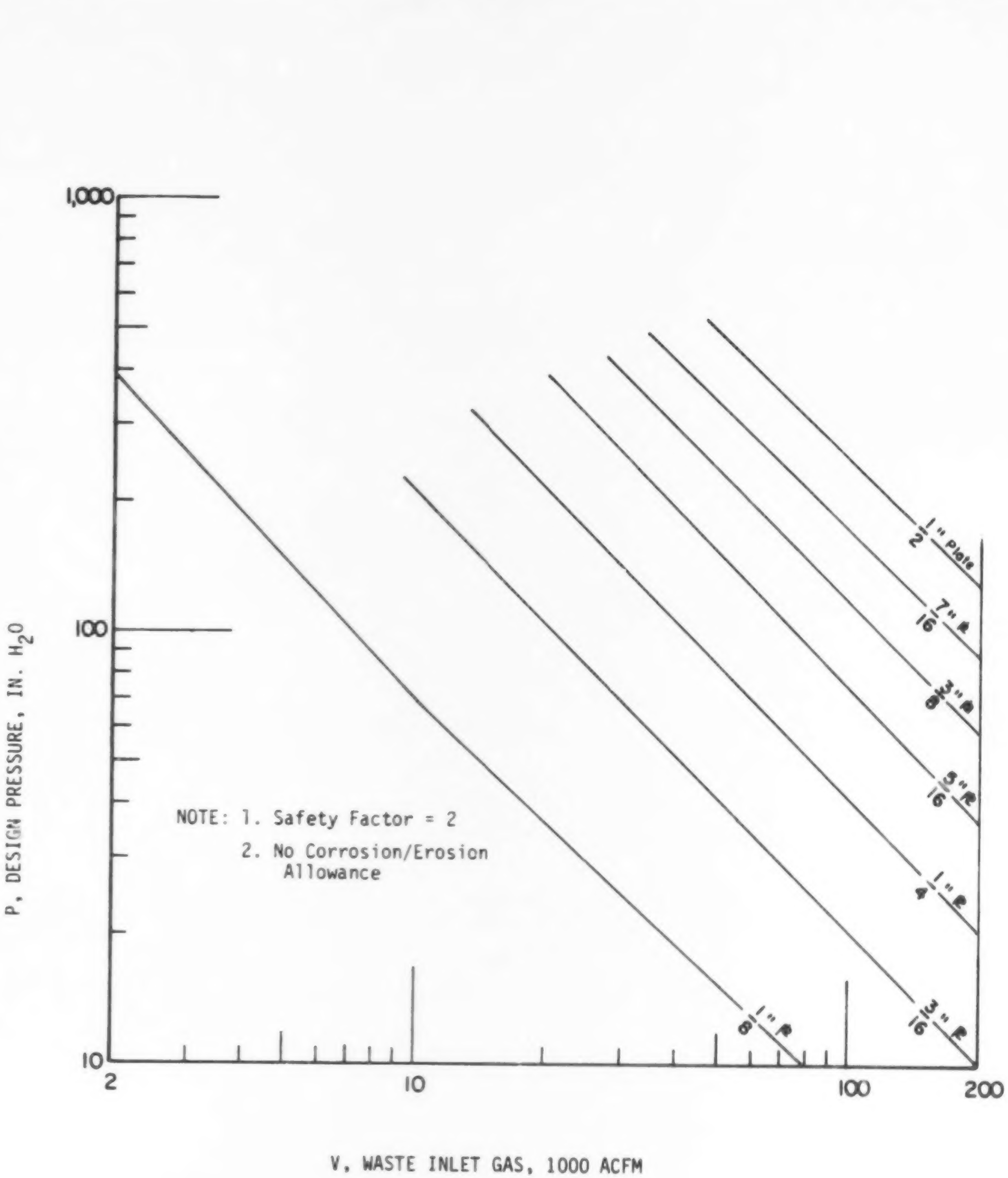


Figure 4-3 METAL THICKNESS REQUIRED VS. VOLUME AND DESIGN PRESSURE

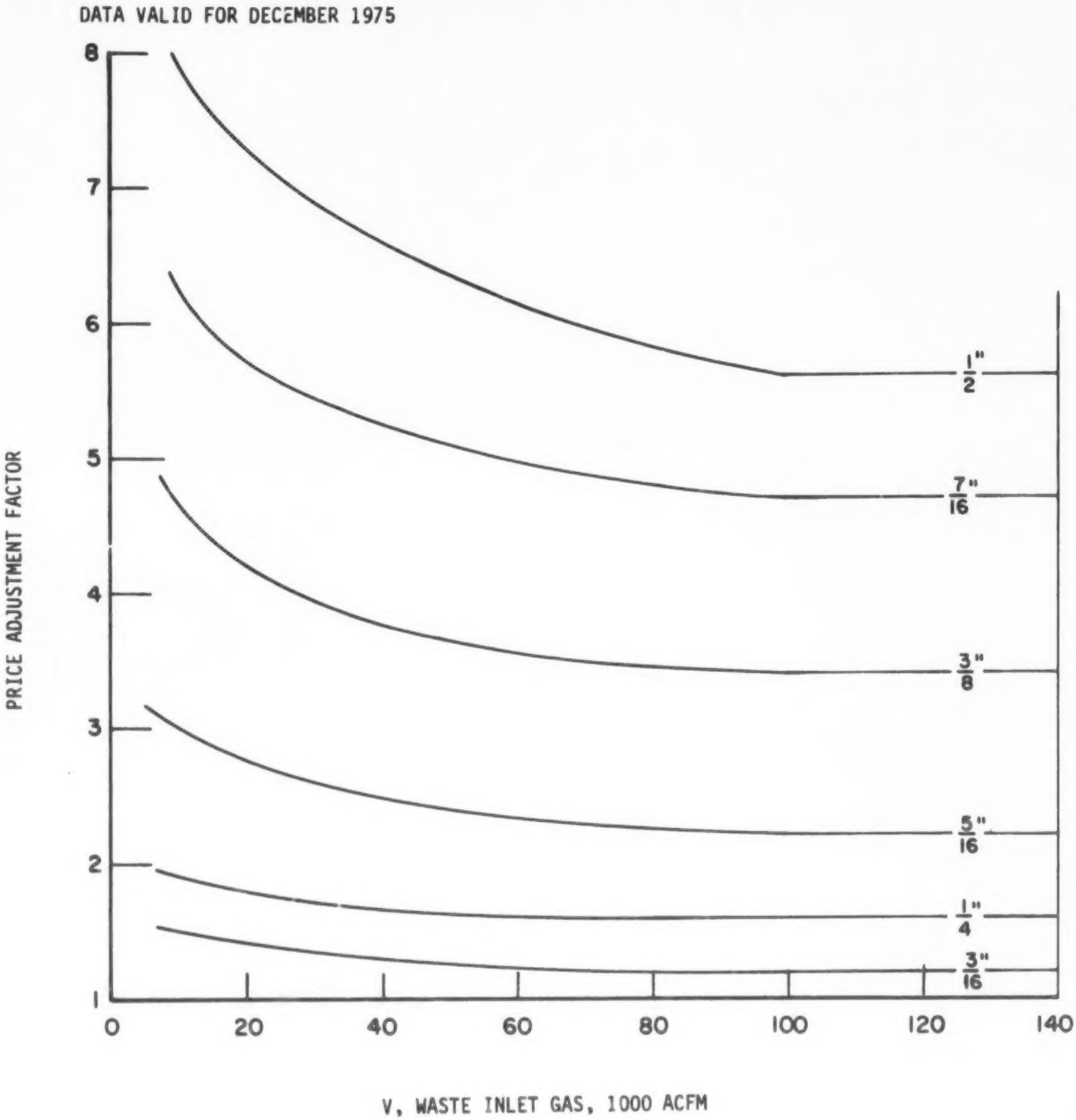


Figure 4-4 PRICE ADJUSTMENT FACTORS VS. PLATE THICKNESS AND VOLUME

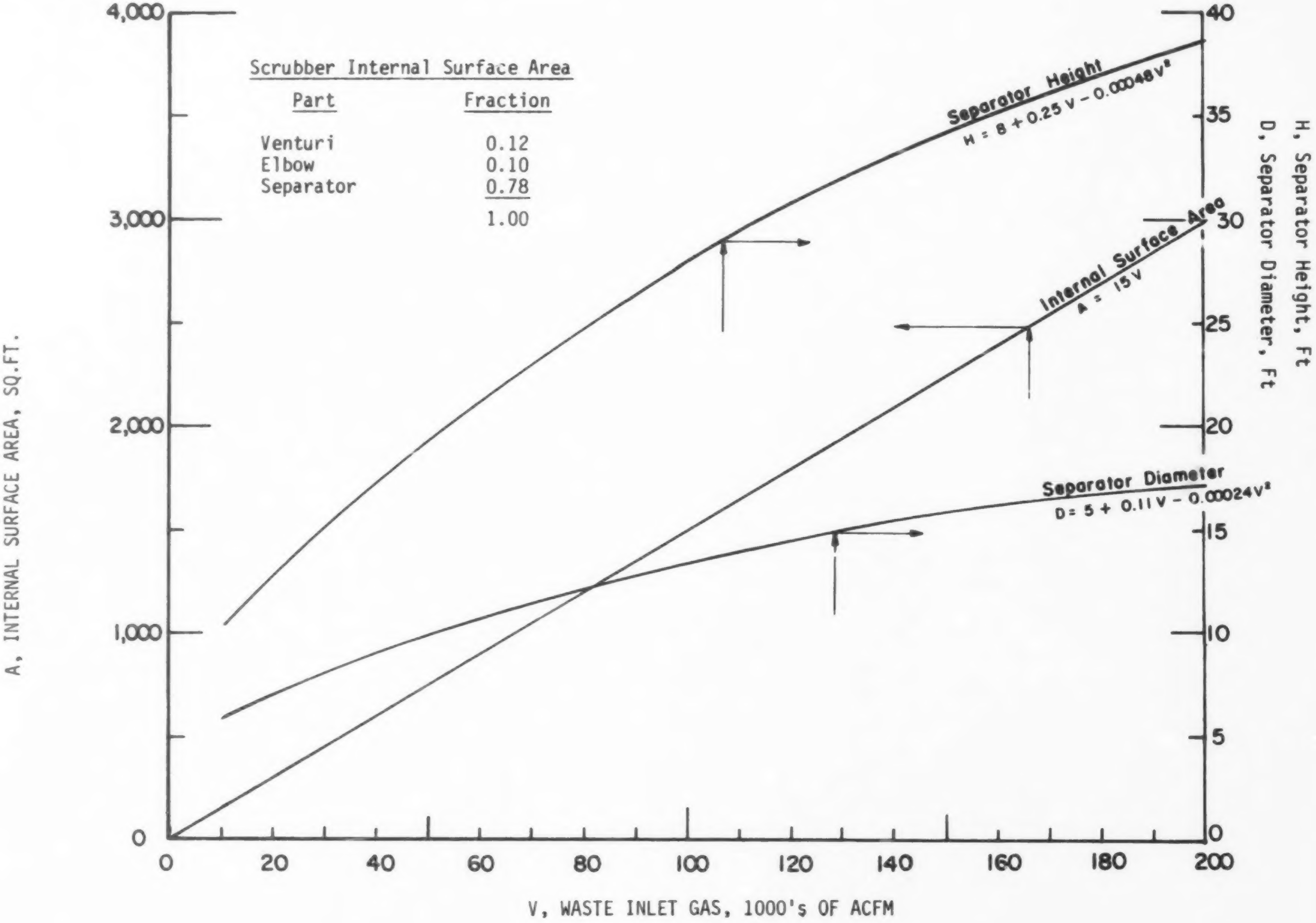
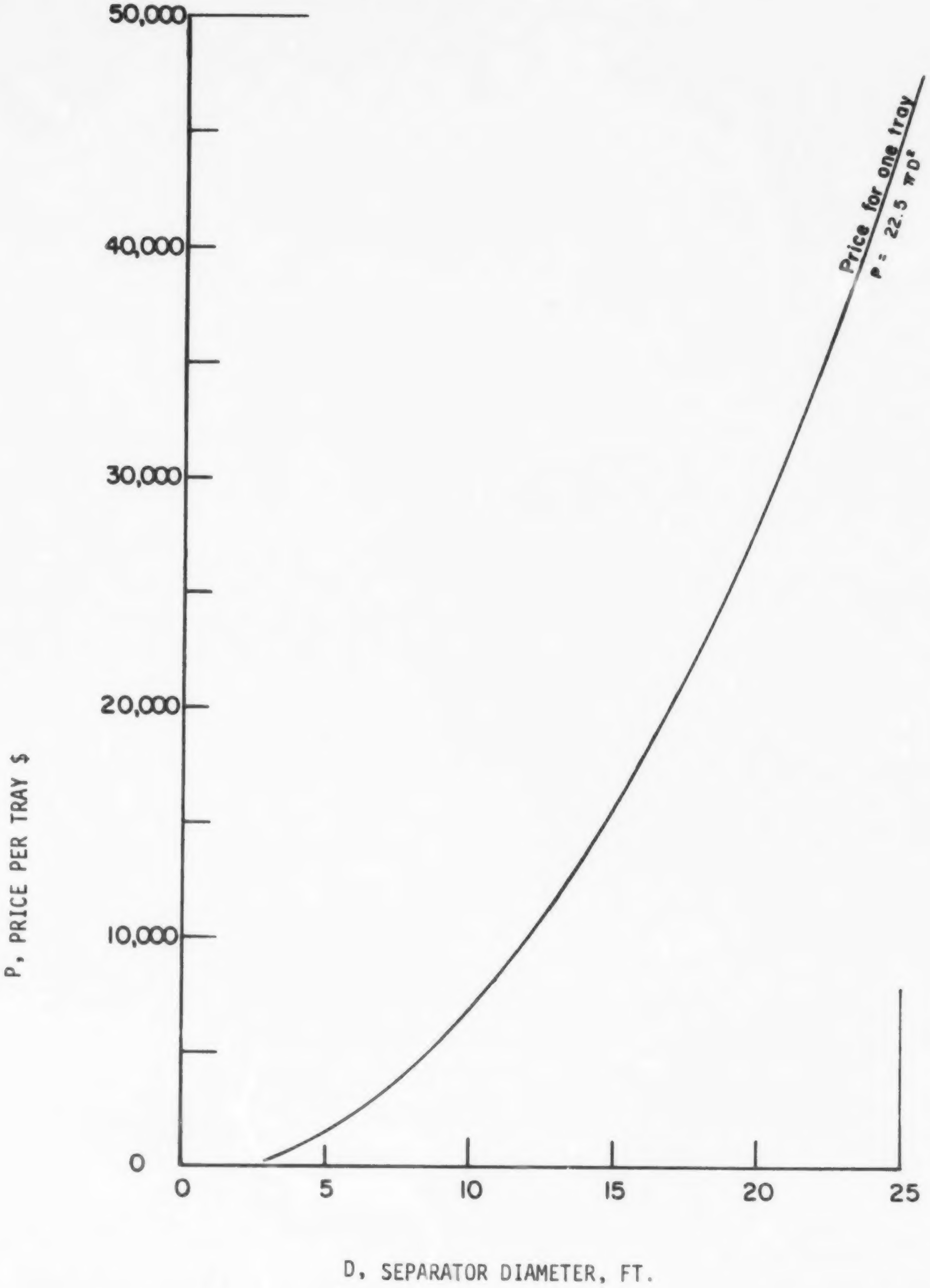


Figure 4-5 SCRUBBER INTERNAL SURFACE AREA AND SEPARATOR DIAMETER AND HEIGHT VS. WASTE INLET GAS VOLUME



DATA VALID FOR DECEMBER 1975

Figure 4-6 INTERNAL GAS COOLER BUBBLE TRAY COST VS. SEPARATOR DIAMETER

4.3 FABRIC FILTERS

Prices for mechanical shaker, pulse-jet, reverse-air, and custom fabric filters (baghouses) are contained in Figures 4-7 through 4-11. Prices are based on net cloth area, which is calculated by dividing the gas volume entering the baghouse by the required air-to-cloth (A/C) ratio (see Table 2-1). For example, to handle 100,000 ACFM at an A/C = 2.0 requires 50,000 ft^2 net cloth area. The price for a reverse-air, pressure-type baghouse at 50,000 ft^2 is $152,000. For stainless steel construction, insulation, and suction-type design, the total price without bags would be:

Baghouse	$152,000
SS	78,000
Insulation	80,000
Suction	16,000
Total	$326,000

The prices for bags may be determined from Tables 4-1 and 4-2. From Table 4-2 obtain factor to calculate gross cloth area (at 50,000 ft^2 the factor is 1.11) and from Table 4-1 obtain the price per square foot for the appropriate cloth and baghouse type. The price of glass bags for the example is thus:

$$50{,}000\ ft^2 \times 1.11 \times \$.40/ft^2 = \$22{,}200$$

Baghouse prices are flange-to-flange, including basic baghouse without bags, 10 foot support clearance, and inlet and exhaust manifolds. Pressure baghouses are designed for 12" W.G. and suction baghouses are designed for 20" W.G. Custom baghouse prices are more a function of specific requirements, than of pressure or suction construction. Hence prices for custom units do not differentiate between pressure or suction. All baghouses are assumed to be factory assembled.

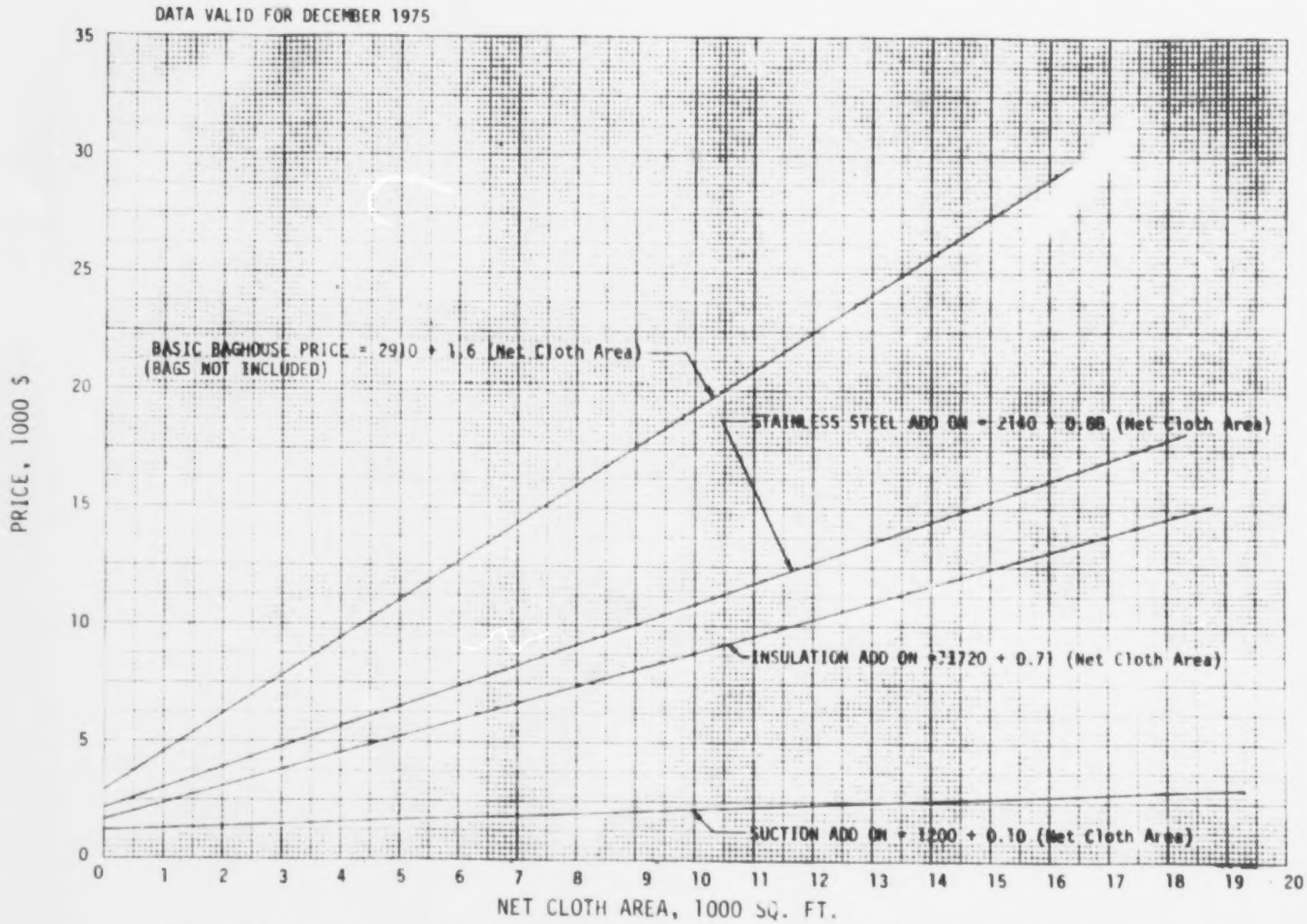

DATA VALID FOR DECEMBER 1975

Figure 4-7 INTERMITTENT, PRESSURE, MECHANICAL SHAKER BAGHOUSE PRICES VS. NET CLOTH AREA

DATA VALID FOR DECEMBER 1975

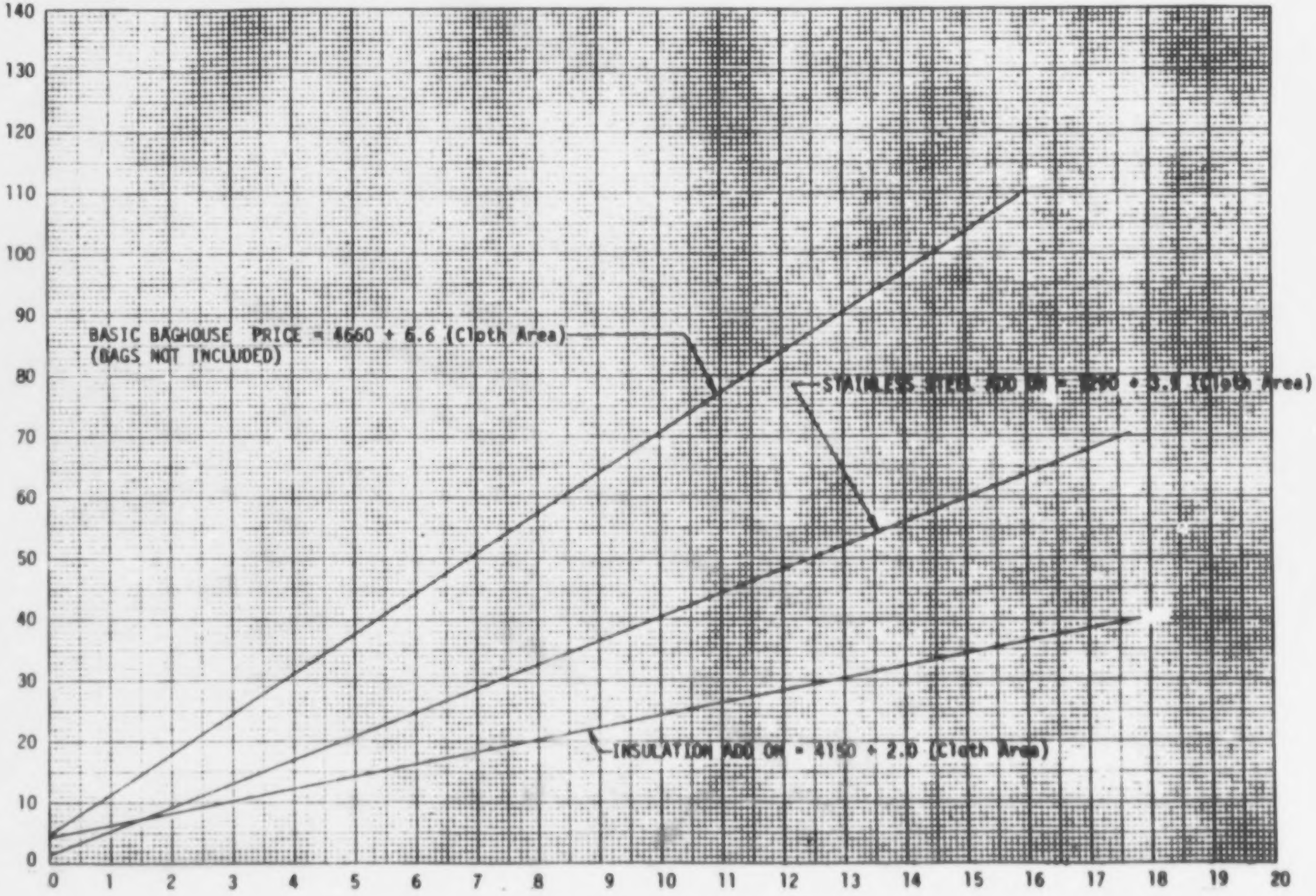


Figure 4-8 CONTINUOUS, SUCTION OR PRESSURE, PULSE JET BAGHOUSE PRICES VS. NET CLOTH AREA

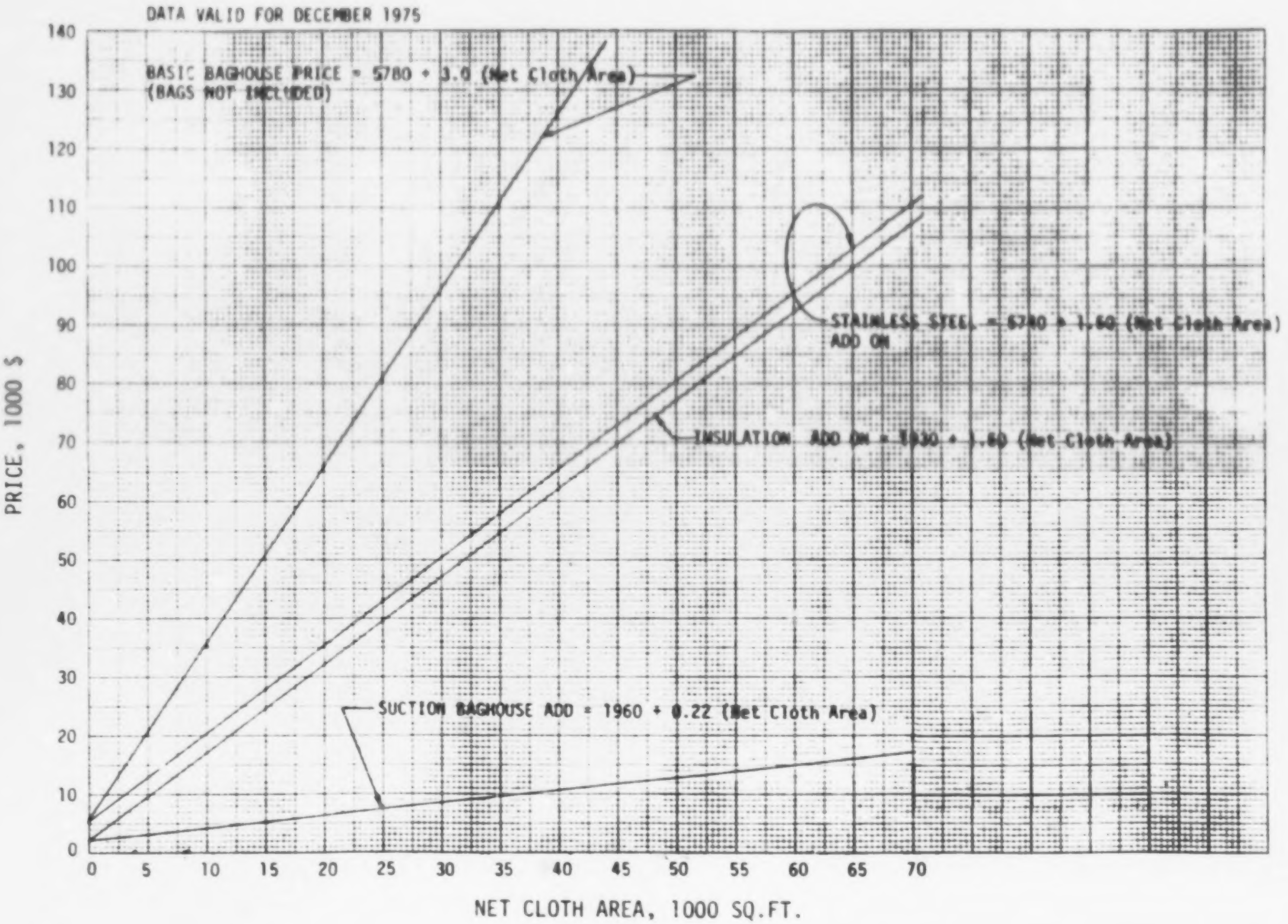


Figure 4-9 CONTINUOUS, PRESSURE, MECHANICAL SHAKER BAGHOUSE PRICES VS. NET CLOTH AREA

DATA VALID FOR DECEMBER 1975

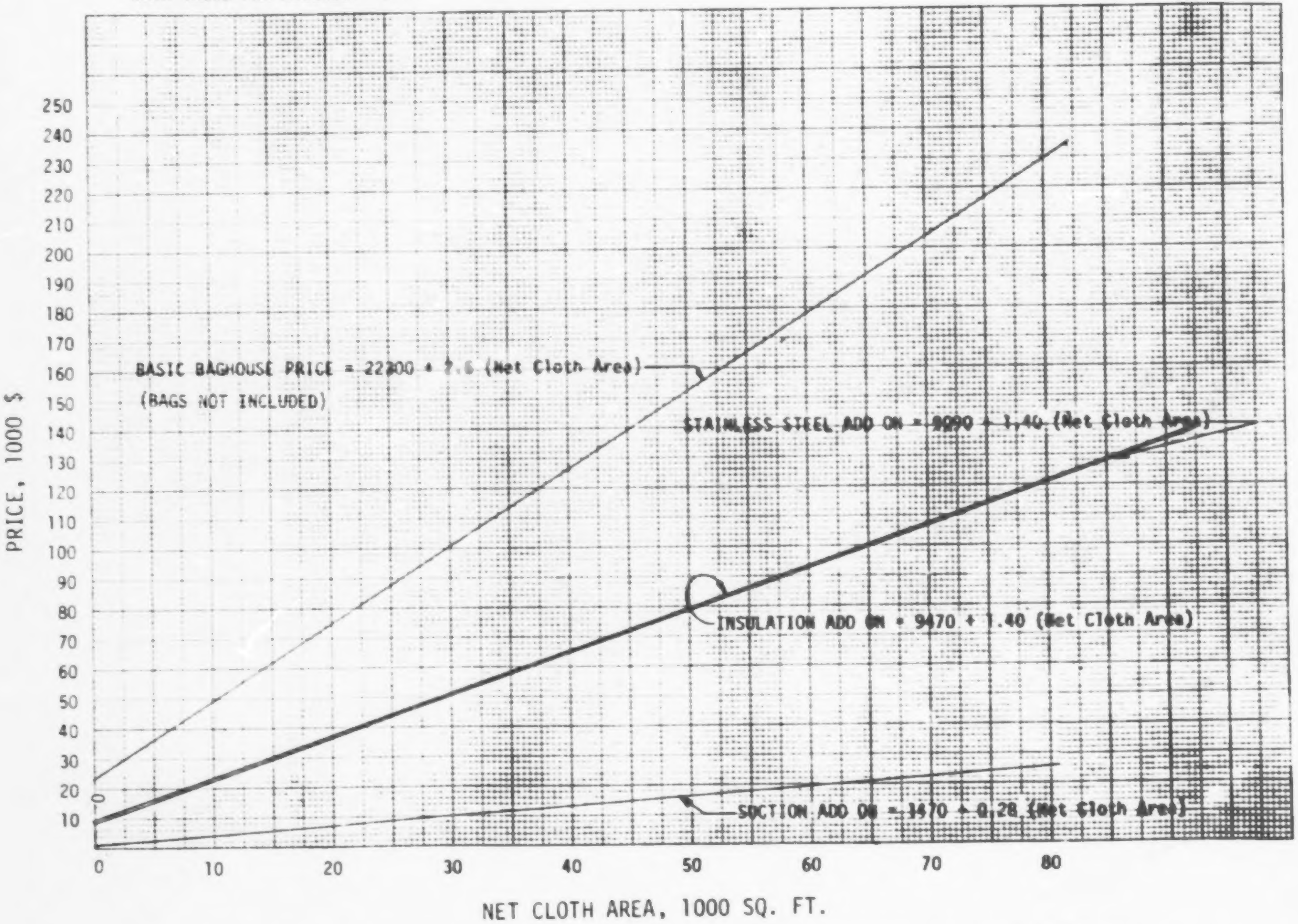


Figure 4-10 CONTINUOUS, PRESSURE, REVERSE AIR BAGHOUSE PRICES VS. NET CLOTH AREA

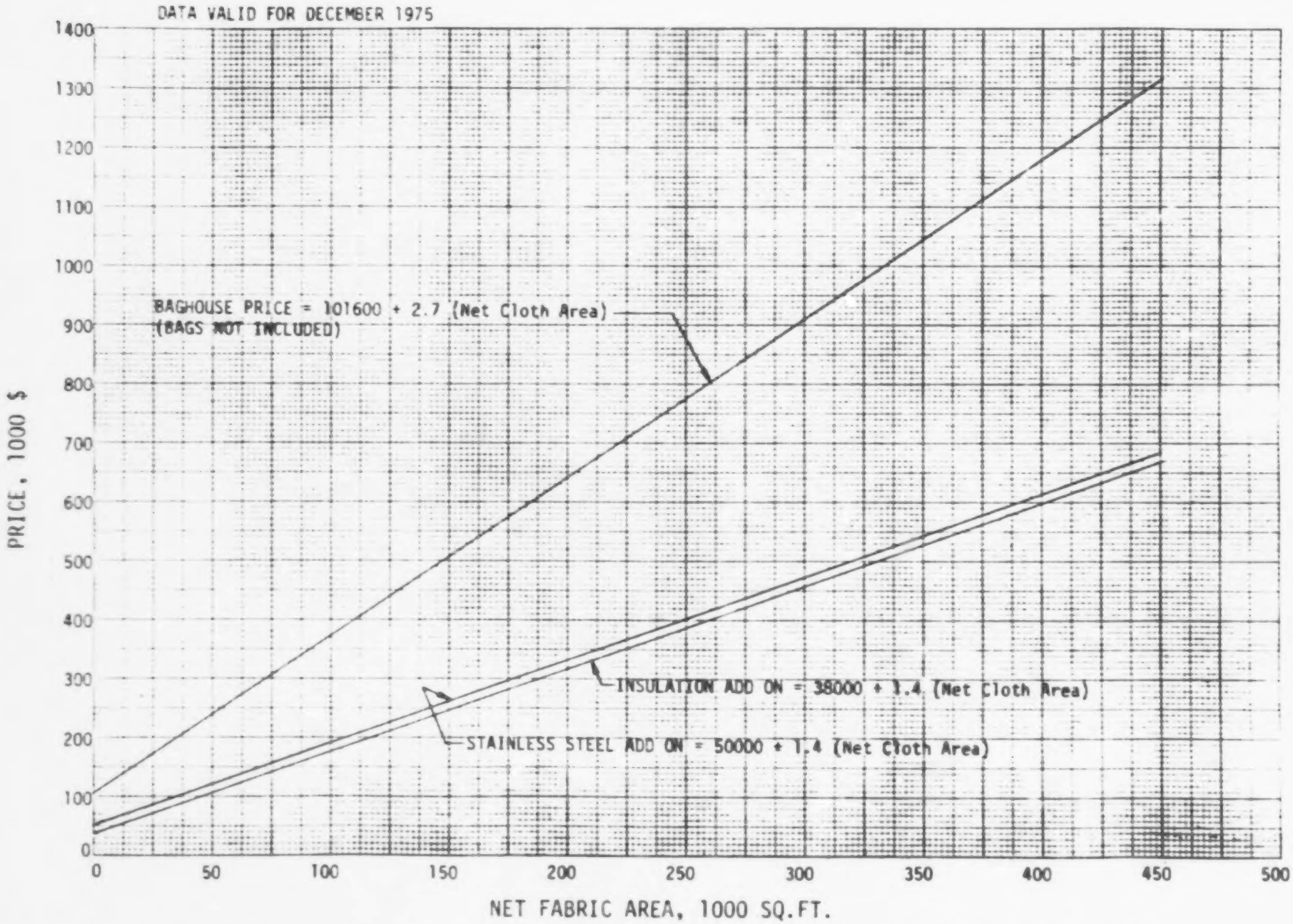


Figure 4-11 CUSTOM PRESSURE OR SUCTION BAGHOUSE PRICES VS. NET CLOTH AREA

Table 4-1 BAG PRICES ($/SQ.FT.)

DATA VALID FOR DECEMBER 1975

CLASS	TYPE	DACRON	ORLON	NYLON	NOMEX	GLASS	POLYPROPYLENE	COTTON
Standard	Mechanical shaker, $< 20000 ft^2$	.35	.60	.70	1.10	.45	.60	.40
	Mechanical shaker, $> 20000 ft^2$	.30	.55	.65	1.00	.40	.50	.35
	Pulse jet*	.55	.90		1.25		.65	
	Reverse air	.30	.55	.65	1.00	.40	.50	.35
Custom	Mechanical shaker	.20	.30	.40	.60	.25	.30	.35
	Reverse air	.20	.30	.40	.60	.25	.30	.35

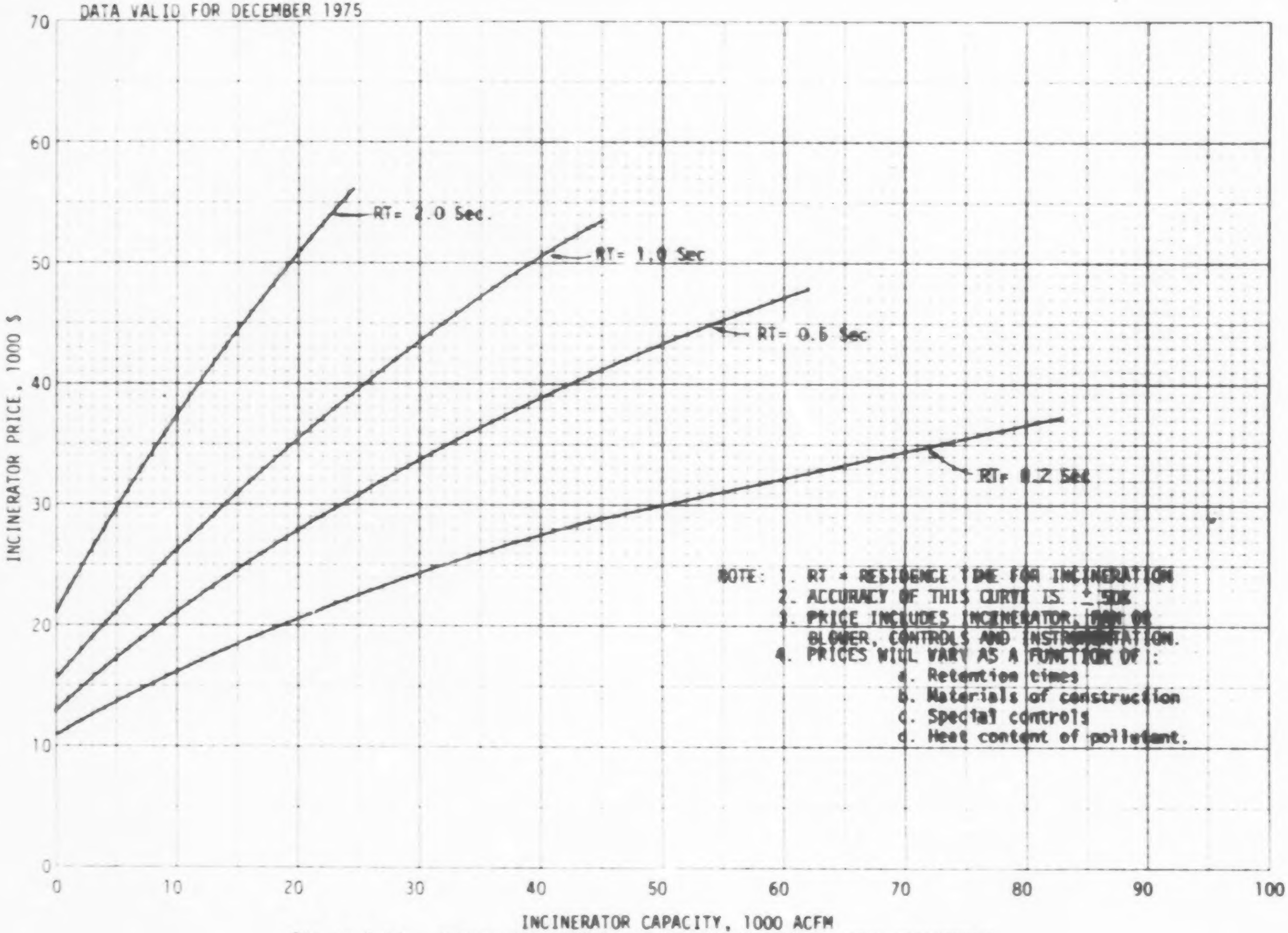
* For heavy felt, multiply price by 1.5

Table 4-2 APPROXIMATE GUIDE TO ESTIMATE GROSS CLOTH AREA

NET CLOTH AREA (Sq.ft.)	GROSS CLOTH AREA (Sq.ft.)
1 - 4000	Multiply by 2
4001 - 12000	" 1.5
12001 - 24000	" 1.25
24001 - 36000	" 1.17
36001 - 48000	" 1.125
48001 - 60000	" 1.11
60001 - 72000	" 1.10
72001 - 84000	" 1.09
84001 - 96000	" 1.08
96001 - 108000	" 1.07
108001 - 132000	" 1.06
132001 - 180000	" 1.05
180001 ON UP	" 1.04

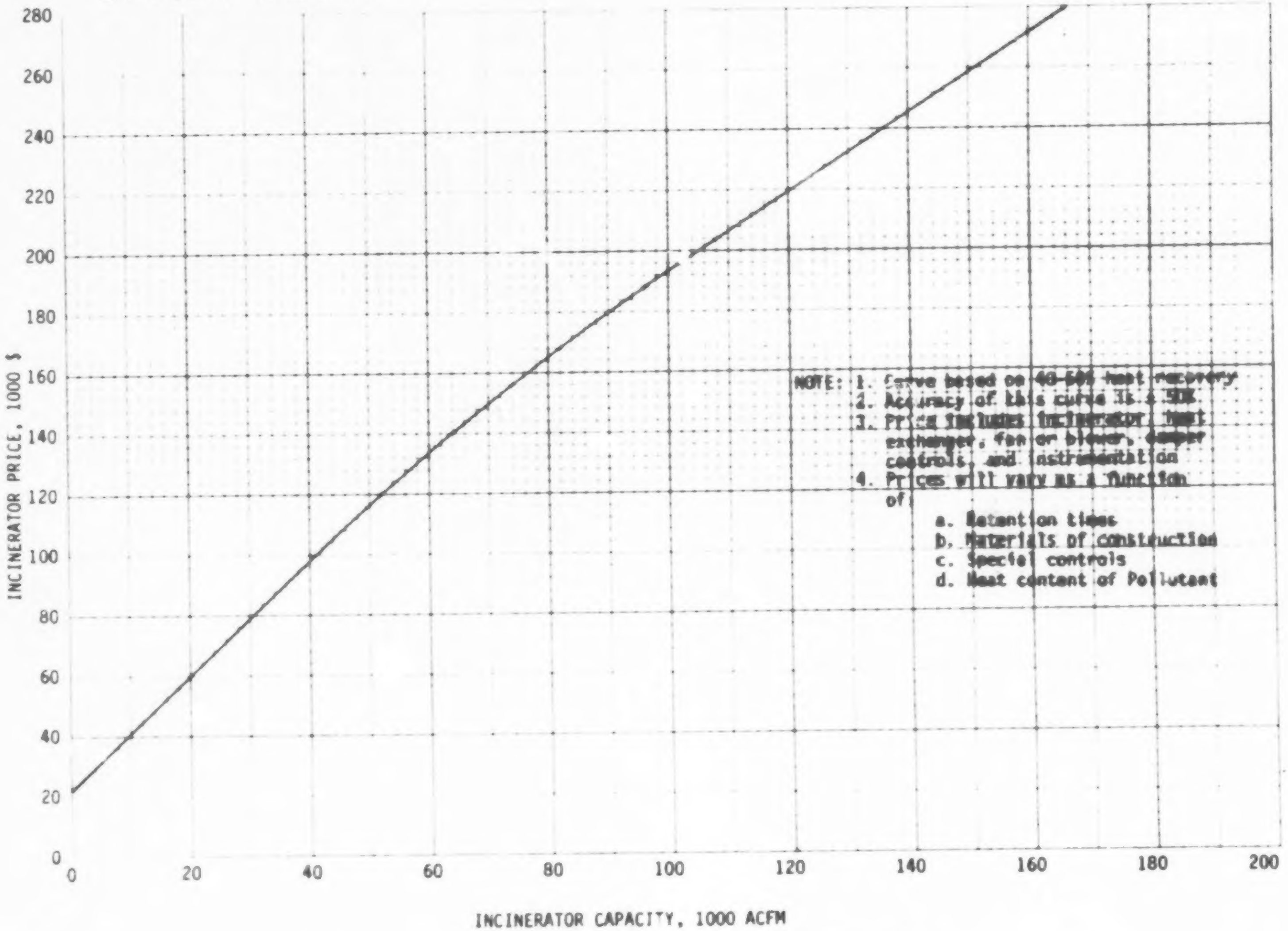
4.4 THERMAL AND CATALYTIC INCINERATORS

Prices for thermal incinerators including refractory linings, are contained in Figures 4-12 and 4-13. Catalytic incinerator prices are found in Figure 4-14. Residence times for thermal incinerators are determined from application requirements for efficiency. The price of a thermal incinerator without heat exchanger for a gas volume of 30,000 ACFM and 0.3 second residence time is $34,000. With a heat exchanger, the price is not as sensitive to residence times, and the price would be $80,000. The price of a custom catalytic unit with heat exchange would be $88,000 at 30,000 ACFM. Gas volumes are measured at operating temperature in the firing chamber.



NOTE:
1. RT = RESIDENCE TIME FOR INCINERATION
2. ACCURACY OF THIS CURVE IS ± 30%
3. PRICE INCLUDES INCINERATOR, FAN OR BLOWER, CONTROLS AND INSTRUMENTATION.
4. PRICES WILL VARY AS A FUNCTION OF :
    a. Retention times
    b. Materials of construction
    c. Special controls
    d. Heat content of pollutant.

Figure 4-12 PRICES FOR THERMAL INCINERATORS WITHOUT HEAT EXCHANGERS



DATA VALID FOR DECEMBER 1975

NOTE:
1. Curve based on 40-60% heat recovery
2. Accuracy of this curve is ± 30%
3. Price includes incinerator, heat exchanger, fan or blower, damper controls, and instrumentation
4. Prices will vary as a function of:
    a. Retention times
    b. Materials of construction
    c. Special controls
    d. Heat content of Pollutant

Figure 4-13 PRICES FOR THERMAL INCINERATORS WITH HEAT EXCHANGERS

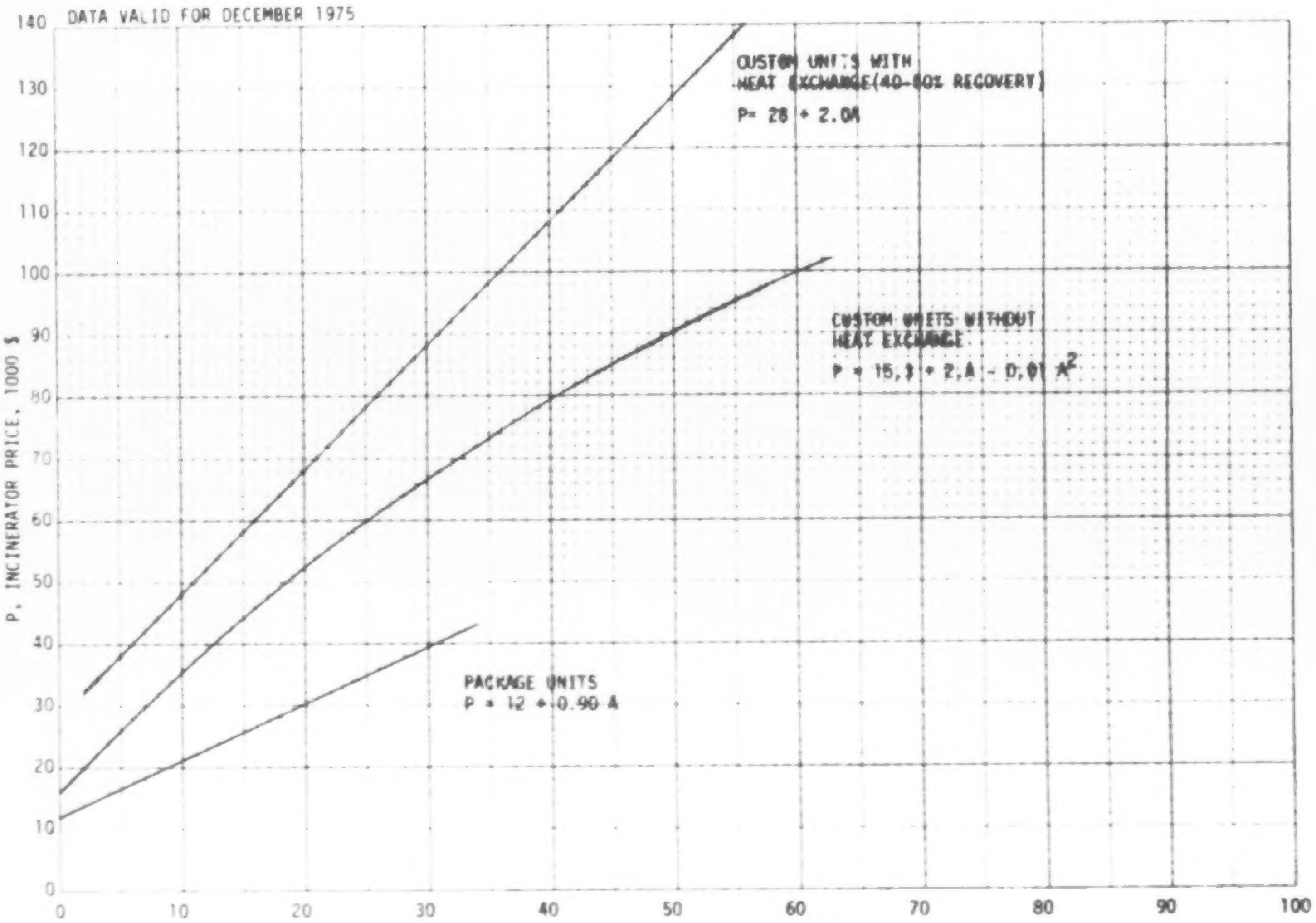


Figure 4-14 CATALYTIC INCINERATOR PRICES

4.5 Adsorbers

Prices for carbon adsorbers are presented in Figures 4-15 and 4-16, as a function of the total number of pounds of carbon in the unit. The total (gross) number of pounds is determined by the adsorption rate and the regeneration rate of the carbon for the emission being controlled. To calculate the net pounds of carbon required for adsorption, first refer to Table 2-3 for a listing of carbon adsorption efficiencies for various solvents. These efficiencies represent the ratio of pounds of solvent collected per 100 pounds of carbon, per hour, under conditions of 100F and 200 cfm. Select the efficiency for the solvent to be controlled (for mixtures of solvents, see the reference noted below). Next determine the rate of solvent emission in pounds per hour. For example, suppose a source produces 35 lb/hr of toluene; since the efficiency for toluene is 7%, then 100 lb of carbon can adsorb 7 lb of toluene per hour. Therefore a total of

$$35 \text{ lb} \times \frac{100 \text{ lb}}{7 \text{ lb}} = 500 \text{ lb of carbon}$$

are required per hour. The air flow rate is figured at 200 cfm per 100 lb of carbon for efficient treatment, so a total of 1000 cfm is required in this case.

Next determine the steam regeneration rate* for the solvent being collected, and calculate the number of beds and gross pounds of carbon required. If the regeneration rate (including cooling) equals the collection rate, two beds will be required, thus the gross weight of carbon must be twice the net weight. If the regeneration rate is one-half the collection rate, three beds will be needed, thus the gross weight of carbon must be 3.0 times the net weight.

---

* See Appendix C, Source No. 88, EPA AP-40
Air Pollution Engineering Manual, p 189 - 198

For the example above, saturated steam at 15 psig and 250F is sufficient to regenerate the carbon. Since the flow rate of steam through the carbon is typically 1/5 to 1/10 the gas velocity, one can figure 20-40 cfm of steam through a 100-lb bed. Under the conditions stated, a cubic foot of steam weighs 0.07235 lb, hence a total of 1.5 - 3.0 lb of steam would pass through each minute. From Figure 124, page 193, of reference 88, the pounds of steam required to recover a pound of toluene is plotted over time. The point on the curve that satisfies the following identity gives the time required for regeneration of 100 lb of carbon:

(# of lb of steam/lb of toluene)x(7 lb toluene) = (2 lb steam/min)x(# of min)

For this application, an approximate rate of steam usage of 13 lb steam/lb toluene gives a regeneration time of about 45 minutes. Cooling of the bed may be accomplished in various ways, but for this example, assume 200 cfm of 100F outside air per 100 lb of carbon. The bed is at 250F (steam temperature) and is to be cooled to 115F, the equilibrium temperature of the working bed. With these conditions, a rough estimate of cooling time would be 30 minutes. Therefore, the total regeneration and cooling time is 75 minutes, for 7 lb of toluene in 100 lb of carbon.

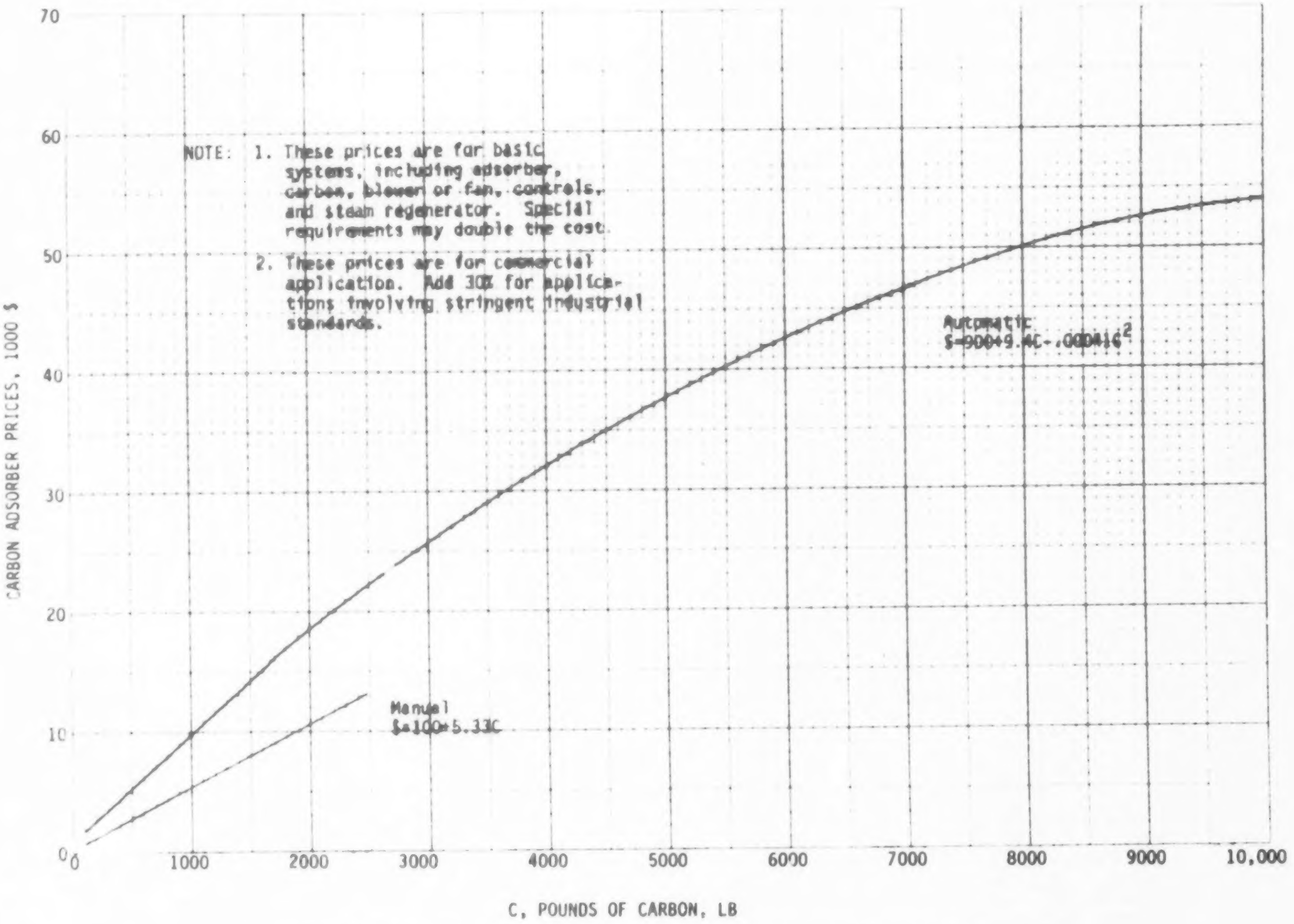
One can then figure that two beds will be required, each having a total cycle time of 150 minutes. Each bed will contain:

(75 min regeneration/60 min adsorption)x(35 lb adsorbed/hr)x(100 lb-hr carbon/7 lb adsorbed) = 625 lb carbon.

The total system thus requires 1250 lb of carbon, and from Figure 4-15, the price of an automatic unit is found to be $12,000 ± 20%.

In Figure 4-15, typical commercial applications include dry cleaning plants and metal cleaning operations, whereas industrial applications include lithography and petrochemical applications. Industrial requirements include heavier materials for high steam or vacuum pressure designs, and more elaborate controls to assure safety against explosions and to prevent hydrocarbon breakthrough.

DATA VALID FOR DECEMBER 1975

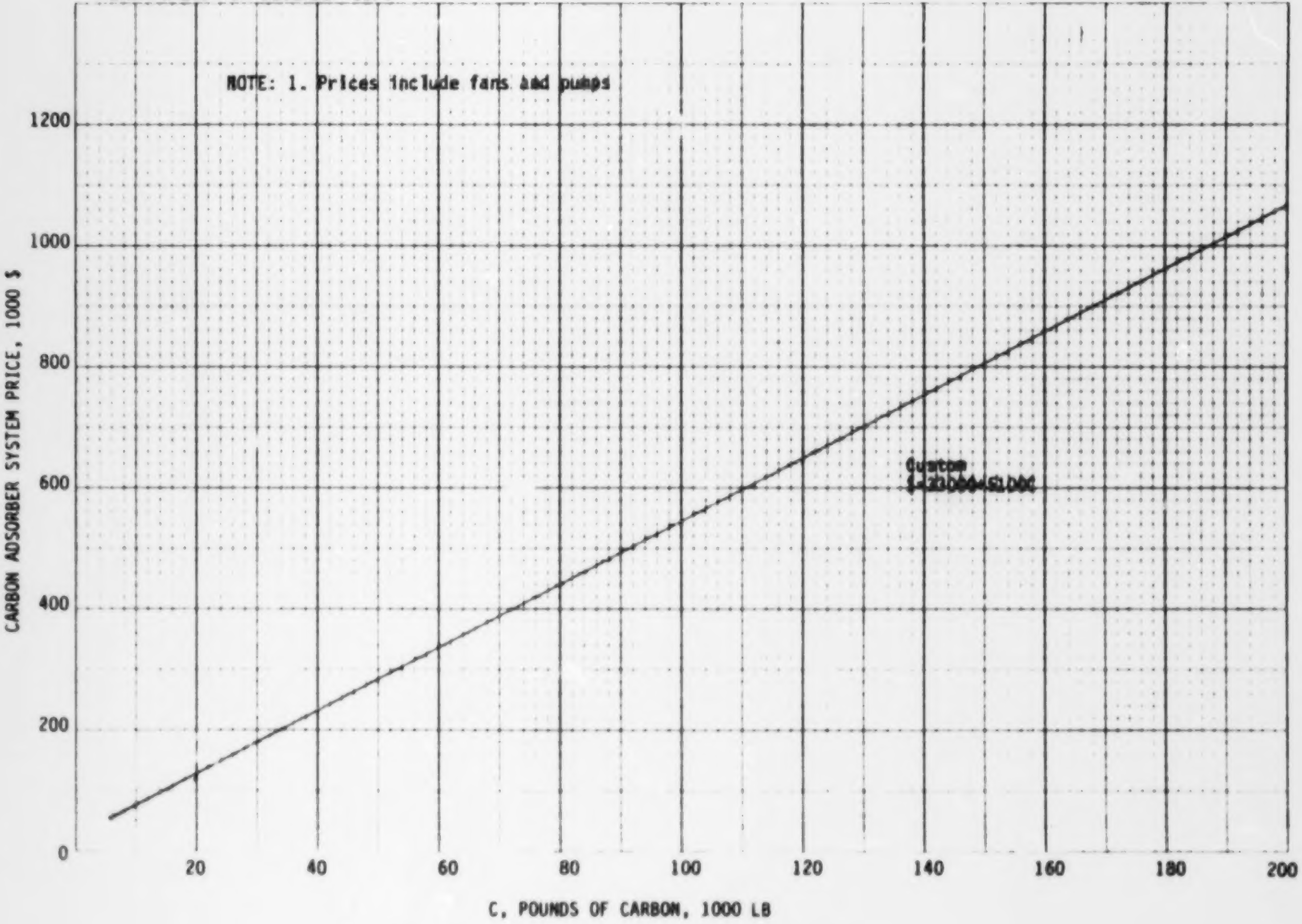


NOTE: 1. These prices are for basic systems, including adsorber, carbon, blower or fan, controls, and steam regenerator. Special requirements may double the cost.

2. These prices are for commercial application. Add 30% for applications involving stringent industrial standards.

Figure 4-15 PRICES FOR PACKAGED STATIONARY BED CARBON ADSORPTION UNITS W/STEAM REGENERATION

DATA VALID FOR DECEMBER 1975



NOTE: 1. Prices include fans and pumps

Figure 4-16 PRICES FOR CUSTOM CARBON ADSORBTION UNITS

4.6 DUCTWORK

4.6.1 Capture Hoods

Figures 4-17 through 4-20 contain data for estimating capture hood costs.

Figure 4-17 gives plate area requirements for rectangular capture hoods and Figure 4-19 gives the corresponding labor costs for 10 Ga. carbon steel construction. Determine the length-to-width ratio (L/W) and the length for a given application, and read the plate area required and the labor cost. For example, if the hood is 20 ft long by 5 ft wide, the L/W = 4, the fabrication labor cost is \$4000, and the plate required is 250 ft^2.

Figure 4-18 gives plate area requirements for circular capture hoods and Figure 4-20 gives the labor costs for 10 Ga. carbon steel construction. Determine the angle of slope,* θ, of the hood cone (or the height-to-diameter ratio) and the diameter of the hood, and read the plate area required and the labor cost. For example, if the hood is 20 ft in diameter and $\theta = 50^0$, the H/D = .6, the fabrication labor cost is \$1900, and the plate required is 550 ft^2.

To determine the total fabricated price, the plate weight must be calculated, including 20% additional for structural supports. The density of 10 Ga. carbon steel is 5.625 lb/ft^2. The density of ¼" plate is about 10.30 lb/ft^2.

Since 10 Ga. (.1382") is usually sufficient for hoods, the total mass of the hoods and structurals in the two examples is:

$$250\ ft^2 \times 5.625\ lb/ft^2 \times 1.2 = \sim 1690\ lb$$

$$550\ ft^2 \times 5.625\ lb/ft^2 \times 1.2 = \sim 3700\ lb$$

---

* To determine angle of slope, see Appendix C, ref. 129, Fan Engineering, especially figure 57, p 114

The material cost, cut to size, is estimate as follows:

		≤ 3/16"	≥ 1/4"
CARBON STEEL	CIRCULAR HOODS	AF + $.108/lb	AF + $.194/lb
	RECTANGULAR HOODS	LG + $.208/lb	LG + $.194/lb

where A is total plate area, not including structurals,

L is length of hood,

F is a pricing factor, and

G is a pricing factor.

F FACTOR

DIAMETER	F
5	$\$.90/\text{ft}^2$
10	.60
15	.50
20	.45
30	.40
40	.40
50	.35
70	.35

G FACTOR

L/W	G
1	$12/ft
2	8
4	4
8	2

Using these formulas, the material cost is calculated to be:

$$550\ \text{ft}^2 \times \$.45/\text{ft}^2 + \$.208/\text{lb} \times 3700\ \text{lb} = \$1000$$

$$20\ \text{ft} \times \$4/\text{ft} + \$.208/\text{lb} \times 1690\ \text{lb} = \$430$$

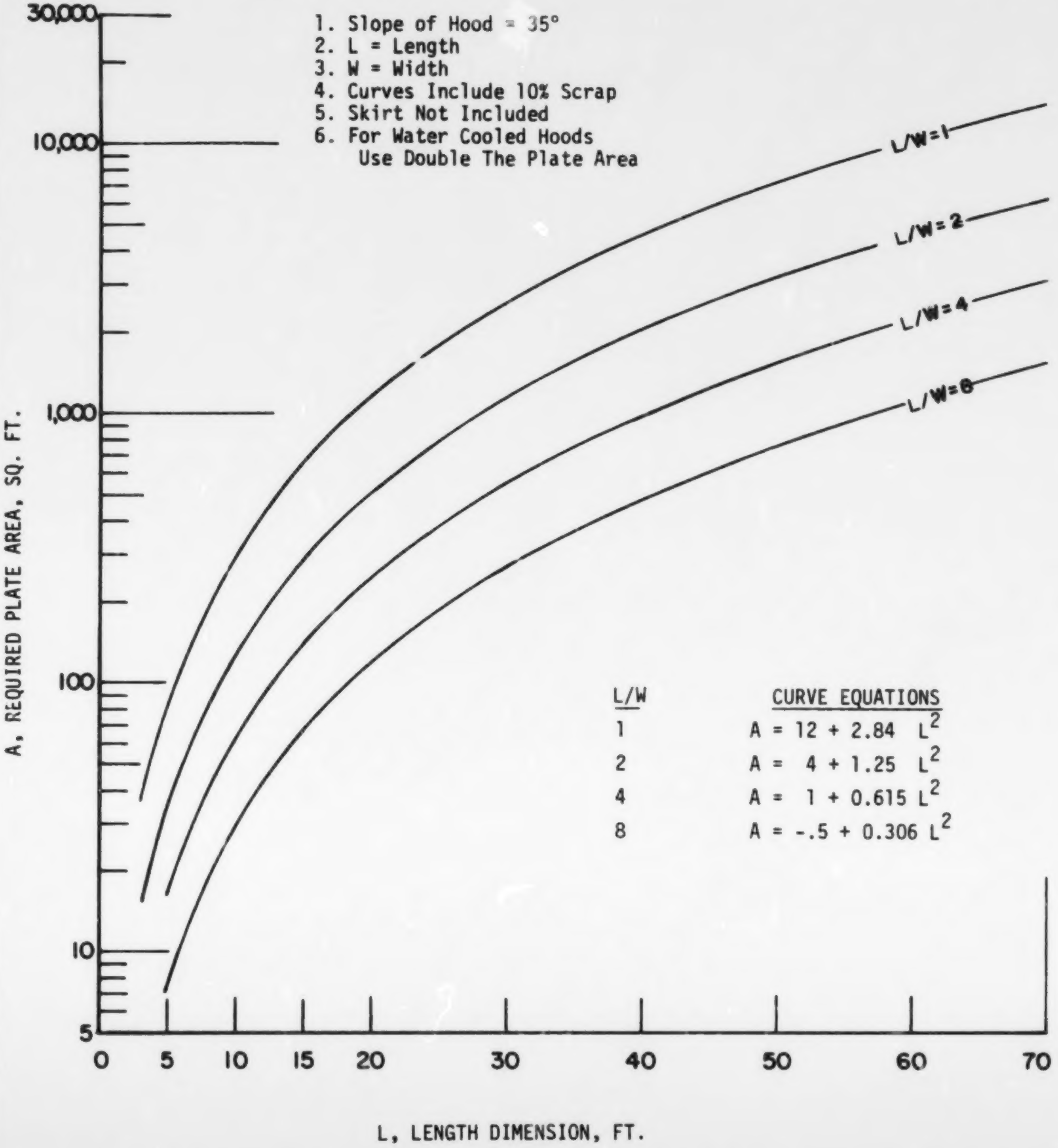
Hence the total price for the two examples is:

35° Rectangular Hood, 20' X 5': $400 + $430 = $830

50° Circular Hood, 20' diam: $1900 + $1000 = $2900

If skirts or booth walls are needed, figure material cost at $.208/lb. The weight of the wall will be the plate area times the material density, plus 20% additional for structurals. For labor cost, figure cost at $.30/lb.

If refractory linings are desired, refer to Section 4.6.5.



1. Slope of Hood = 35°
2. L = Length
3. W = Width
4. Curves Include 10% Scrap
5. Skirt Not Included
6. For Water Cooled Hoods
   Use Double The Plate Area

L/W	CURVE EQUATIONS
1	$A = 12 + 2.84\ L^2$
2	$A = 4 + 1.25\ L^2$
4	$A = 1 + 0.615\ L^2$
8	$A = -.5 + 0.306\ L^2$

Figure 4-17 RECTANGULAR CAPTURE HOODS PLATE AREA REQUIREMENTS VS. HOOD LENGTH AND L/W

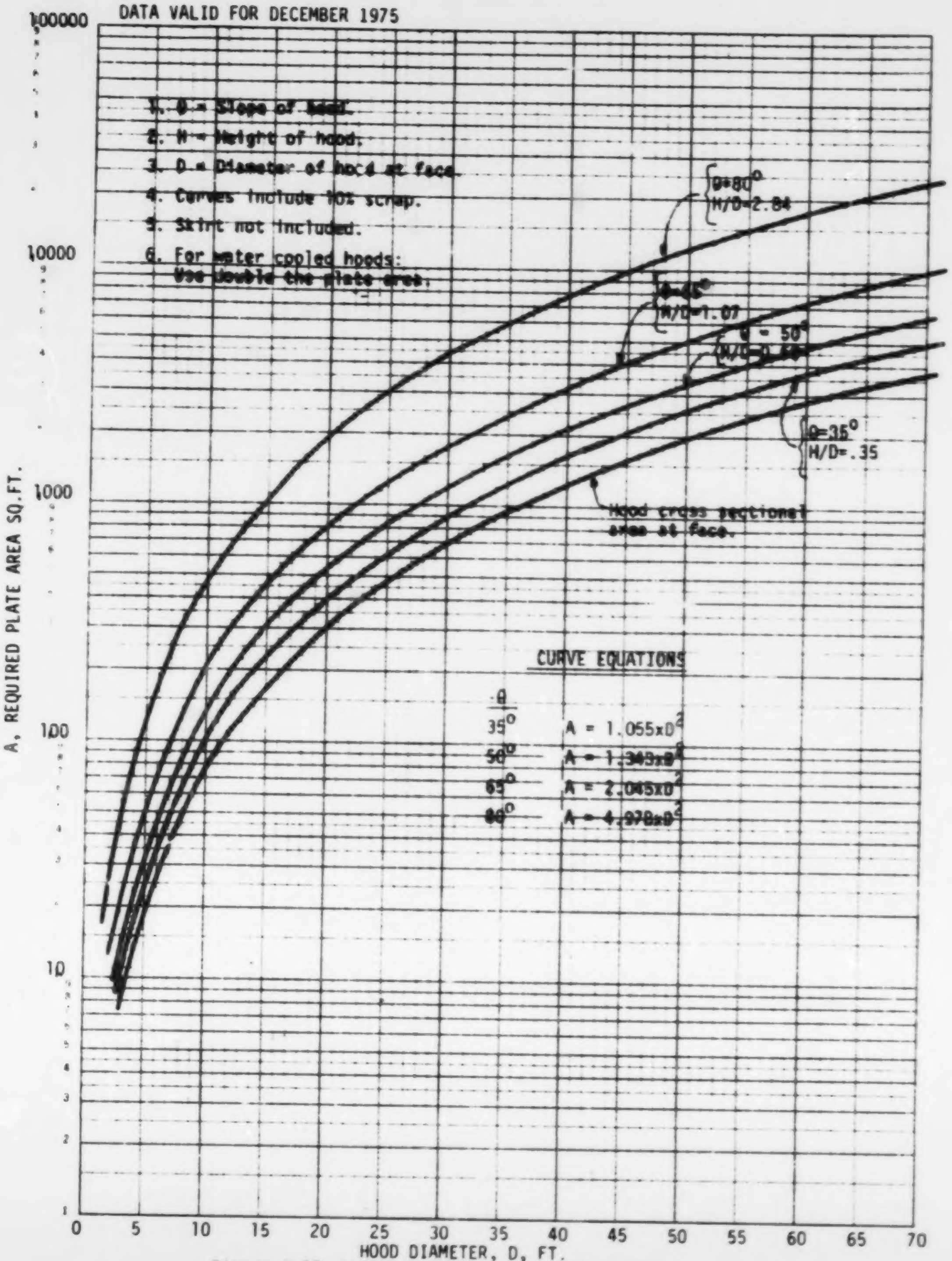
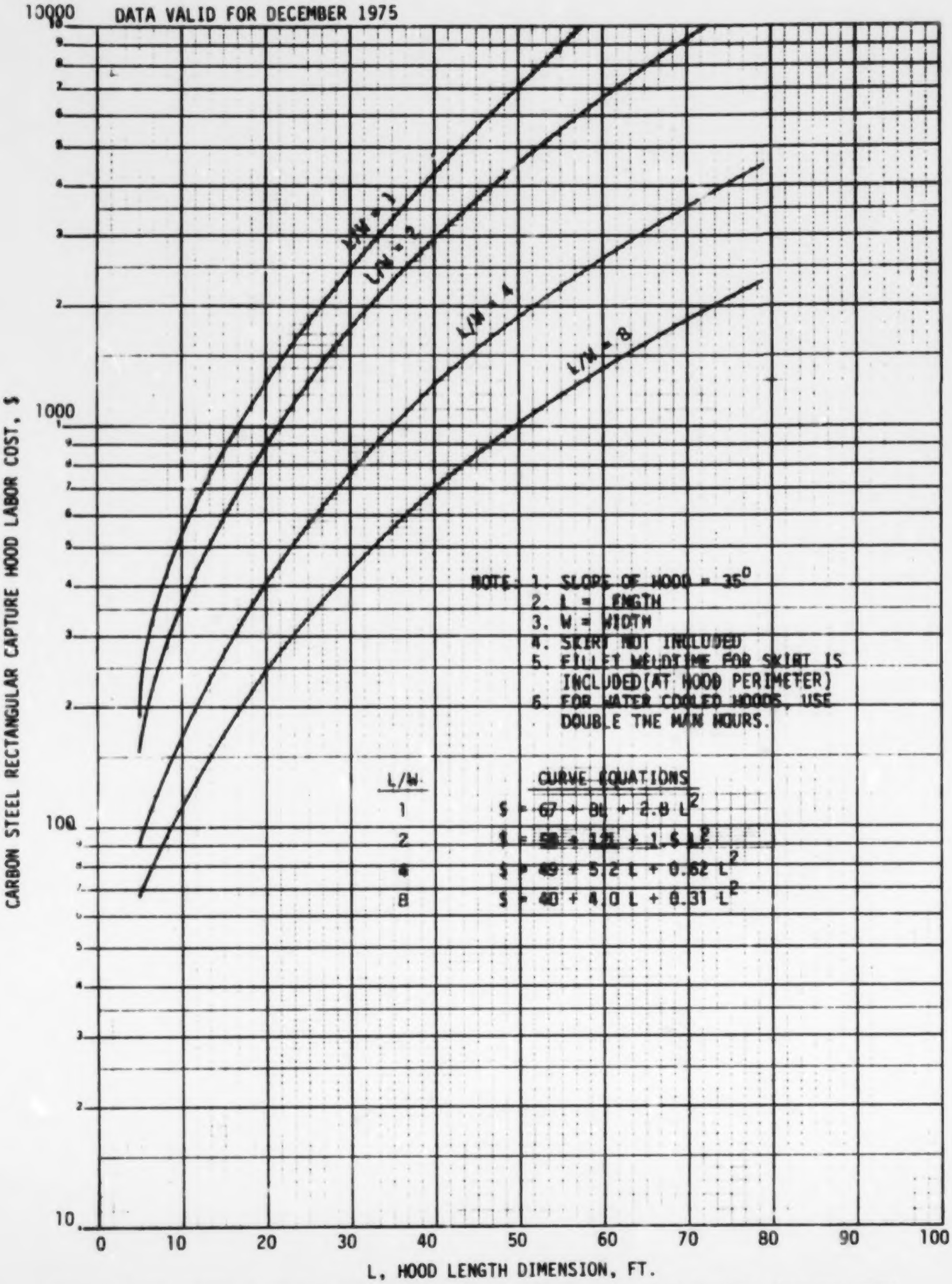


Figure 4-18 CIRCULAR HOODS PLATE REQUIREMENTS

DATA VALID FOR DECEMBER 1975



NOTE: 1. SLOPE OF HOOD = 35°
2. L = LENGTH
3. W = WIDTH
4. SKIRT NOT INCLUDED
5. FILLET WELDTIME FOR SKIRT IS INCLUDED (AT HOOD PERIMETER)
6. FOR WATER COOLED HOODS, USE DOUBLE THE MAN HOURS.

L/W	CURVE EQUATIONS
1	$\$ = 67 + 8L + 2.8\ L^2$
2	$\$ = 58 + 12L + 1.5\ L^2$
4	$\$ = 49 + 5.2\ L + 0.62\ L^2$
8	$\$ = 40 + 4.0\ L + 0.31\ L^2$

Figure 4-19 LABOR COST FOR FABRICATED 10 GA. CARBON STEEL RECTANGULAR CAPTURE HOODS

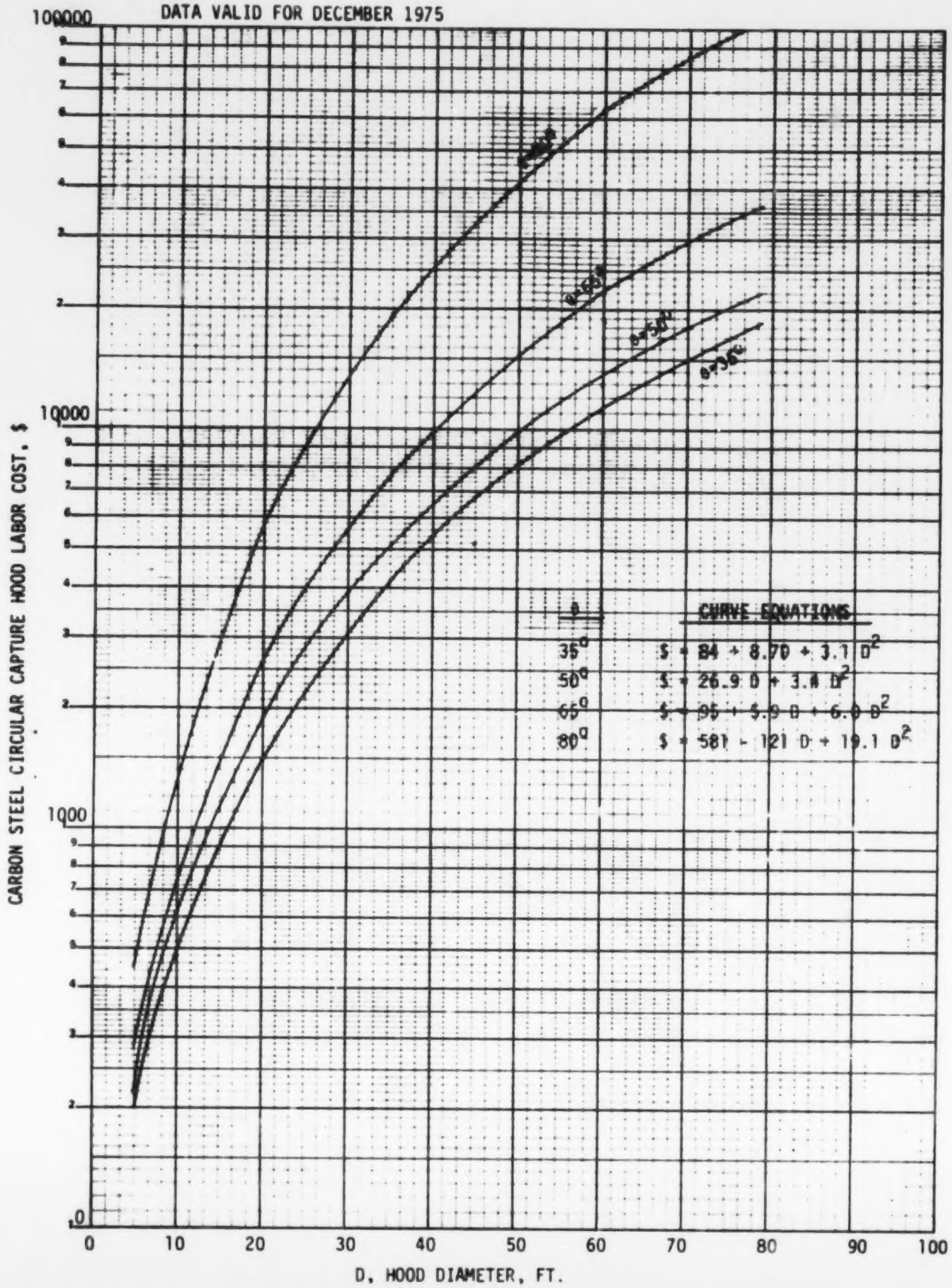


Figure 4-20 LABOR COST FOR FABRICATED 10 GA. CARBON STEEL CIRCULAR CAPTURE HOODS

4.6.2 Straight Duct

Figure 4-21 gives the price for fabricated carbon steel duct in $ per foot as a function of duct diameter and material thickness. A 48" duct, ¼" thick costs $73/ft. Hence 100 ft costs $7300. Figure 4-22 gives prices for stainless steel construction and Figure 4-23 gives prices for water cooled carbon steel duct.

For refractory lined duct, refer to Section 4.6.5.

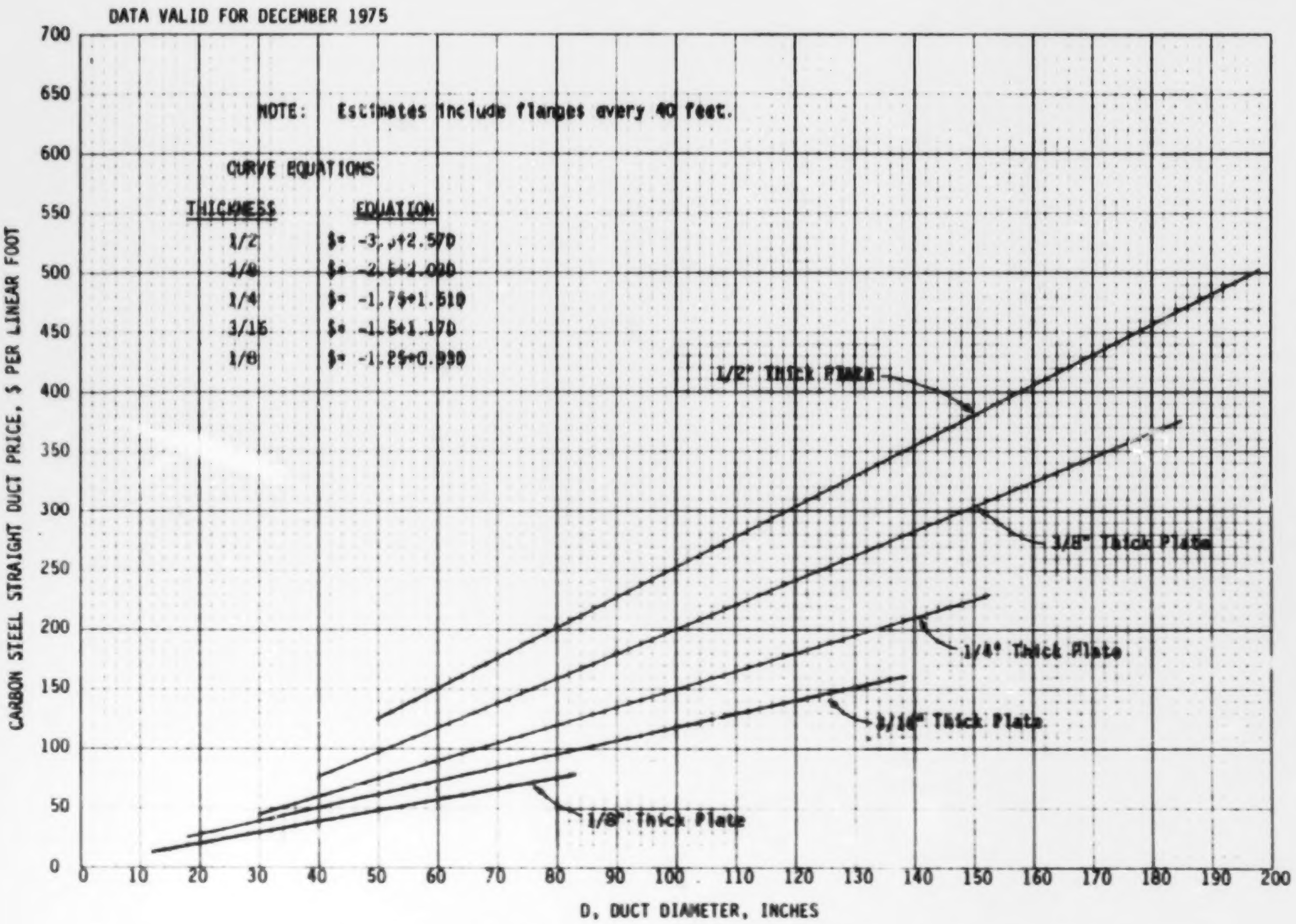


Figure 4-21 CARBON STEEL STRAIGHT DUCT FABRICATION PRICE PER LINEAR FOOT VS. DUCT DIAMETER AND PLATE THICKNESS

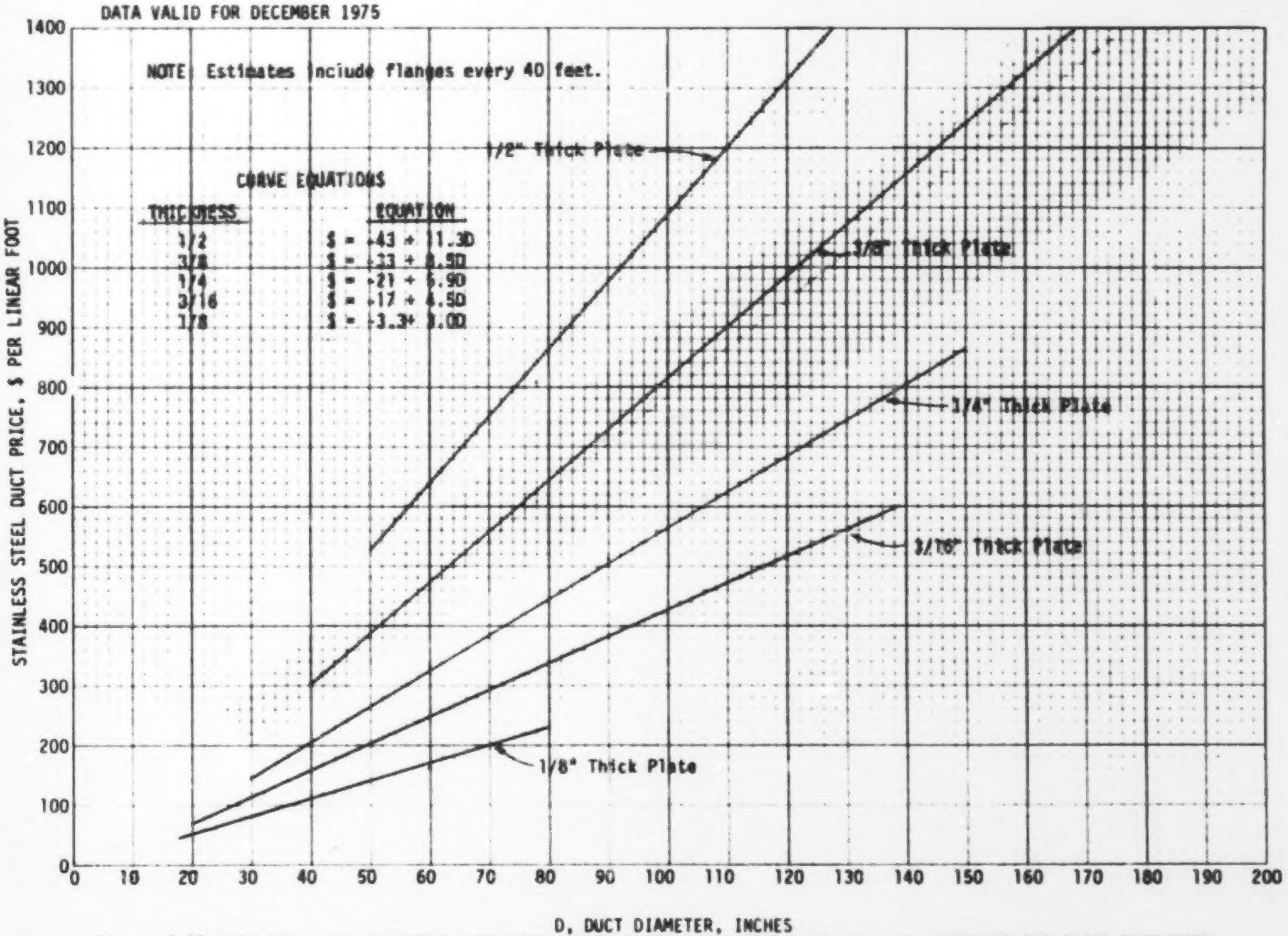


Figure 4-22 STAINLESS STEEL STRAIGHT DUCT FABRICATION PRICE PER LINEAR FOOT VS. DUCT DIAMETER AND PLATE THICKNESS

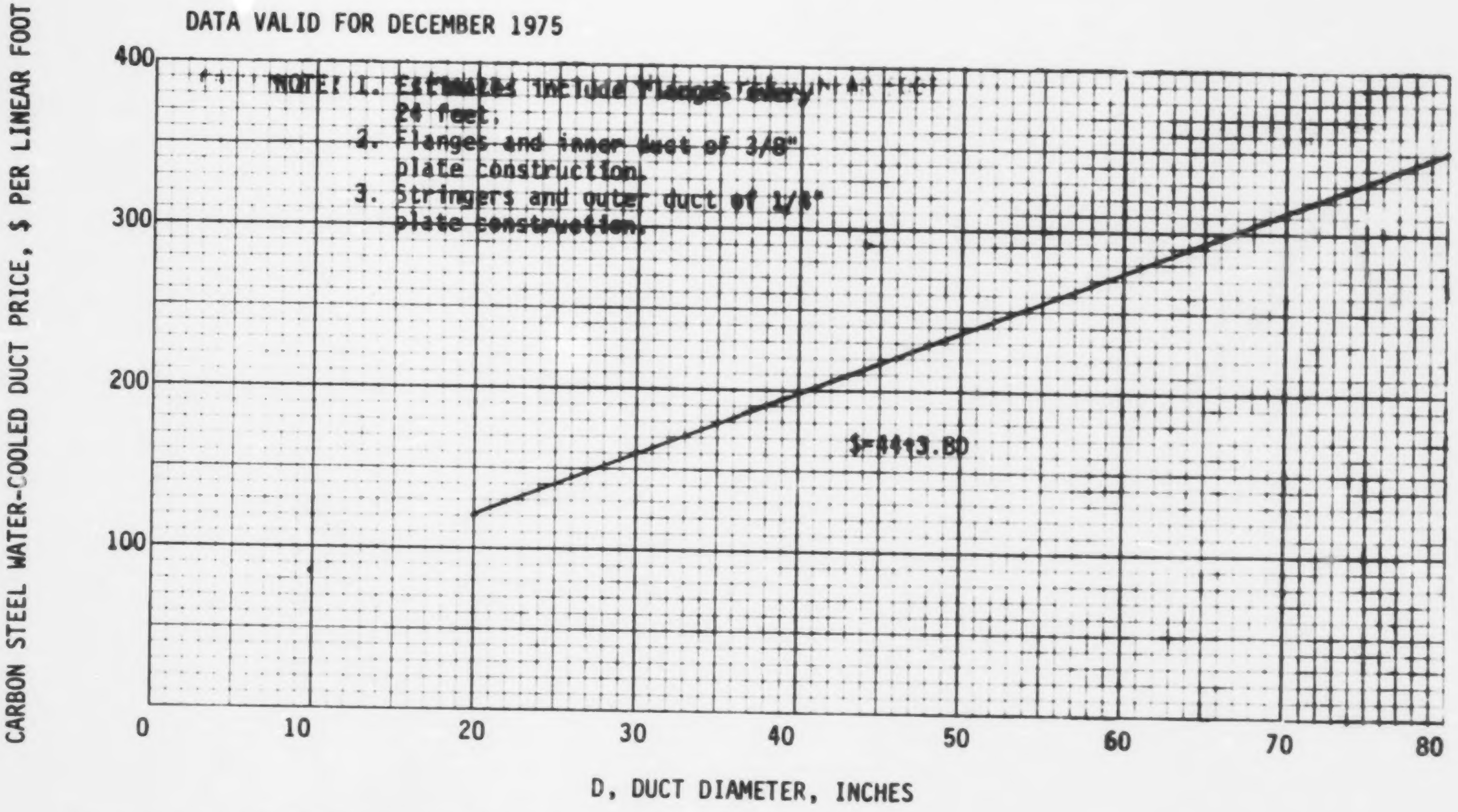


Figure 4-23 WATER COOLED CARBON STEEL STRAIGHT DUCT FABRICATION PRICE PER FOOT VS. DUCT DIAMETER

4.6.3 Elbow Duct, Tees, and Transitions

Figures 4-24 and 4-25 contain prices for carbon steel and stainless steel elbow duct, respectively. Prices are a function of duct diameter and material thickness.

For tees, the price will be 1/3 the corresponding price of an elbow having the same diameter and thickness. For transitions, the price will be ½ the corresponding elbow price (use large diameter for sizing).

For refractory lined elbows refer to Section 4.6.5.

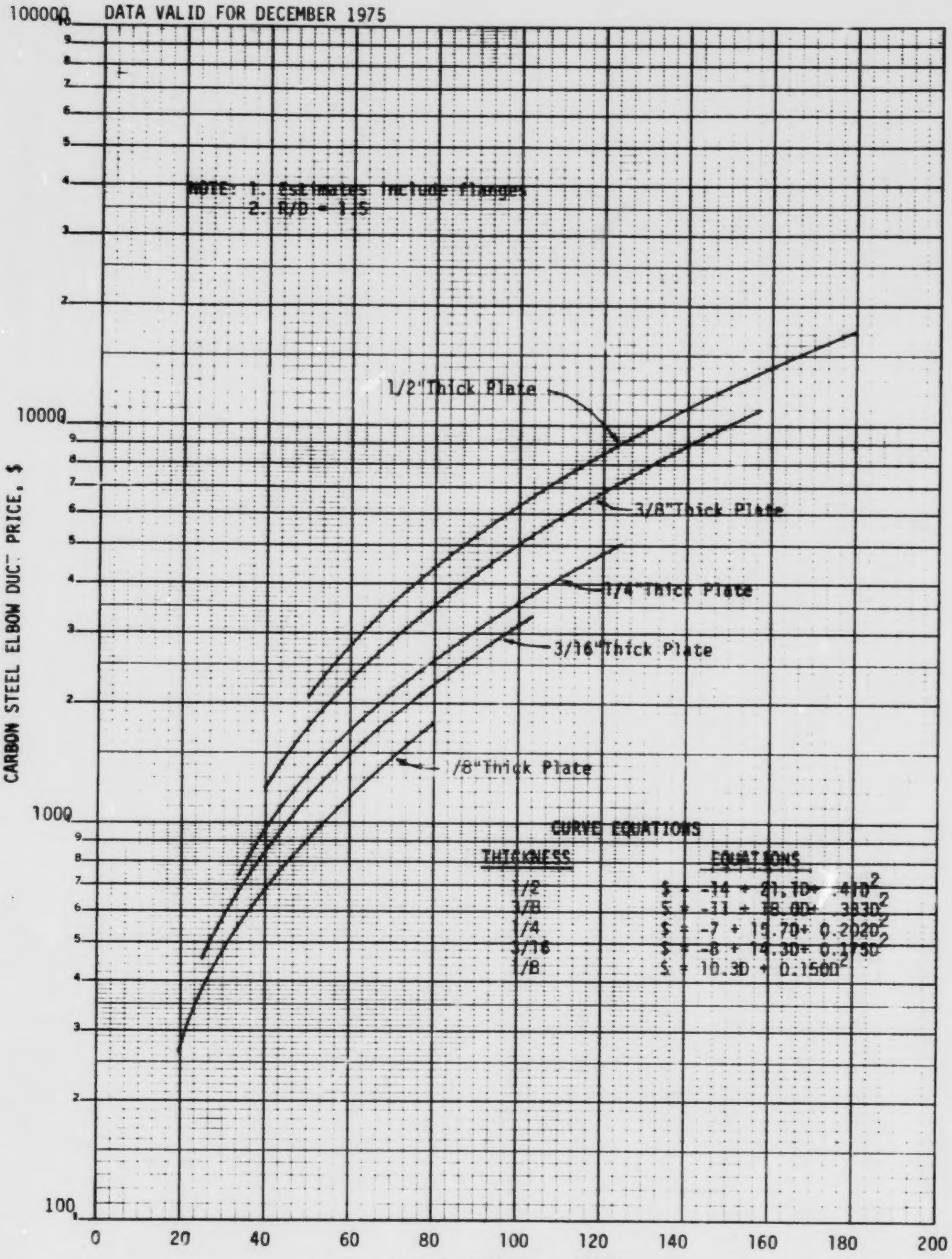
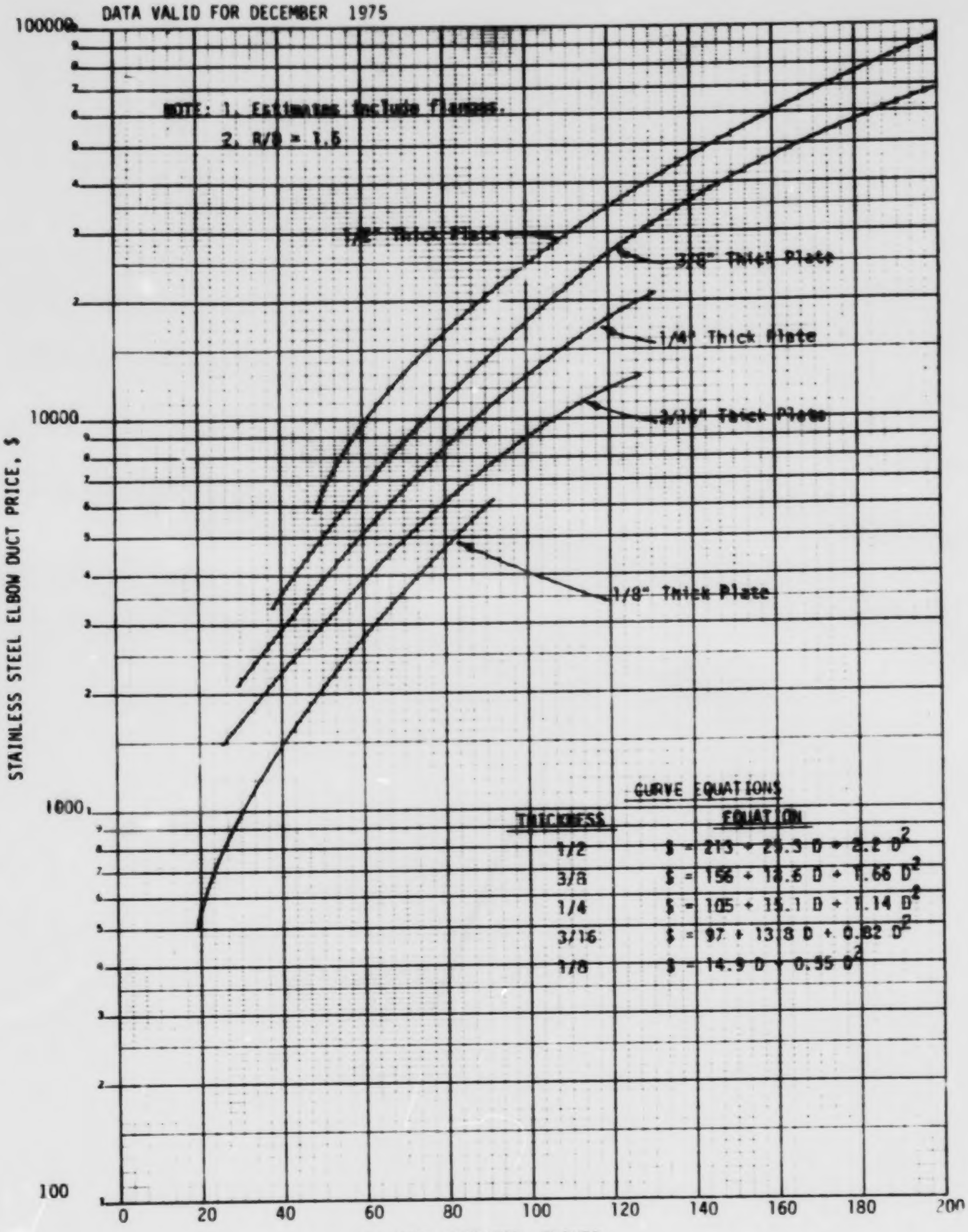


Figure 4-24 CARBON STEEL ELBOW DUCT PRICE VS. DUCT DIAMETER AND PLATE THICKNESS



CURVE EQUATIONS

THICKNESS	EQUATION
1/2	$\$ = 213 + 29.3\,D + 2.2\,D^2$
3/8	$\$ = 156 + 18.6\,D + 1.66\,D^2$
1/4	$\$ = 105 + 15.1\,D + 1.14\,D^2$
3/16	$\$ = 97 + 13.8\,D + 0.82\,D^2$
1/8	$\$ = 14.9\,D + 0.55\,D^2$

Figure 4-25 STAINLESS STEEL ELBOW DUCT PRICE VS. DUCT DIAMETER AND PLATE THICKNESS

4.6.4 Expansion Joints

Figure 4-26 contains prices for expansion joints as a function of duct diameter.

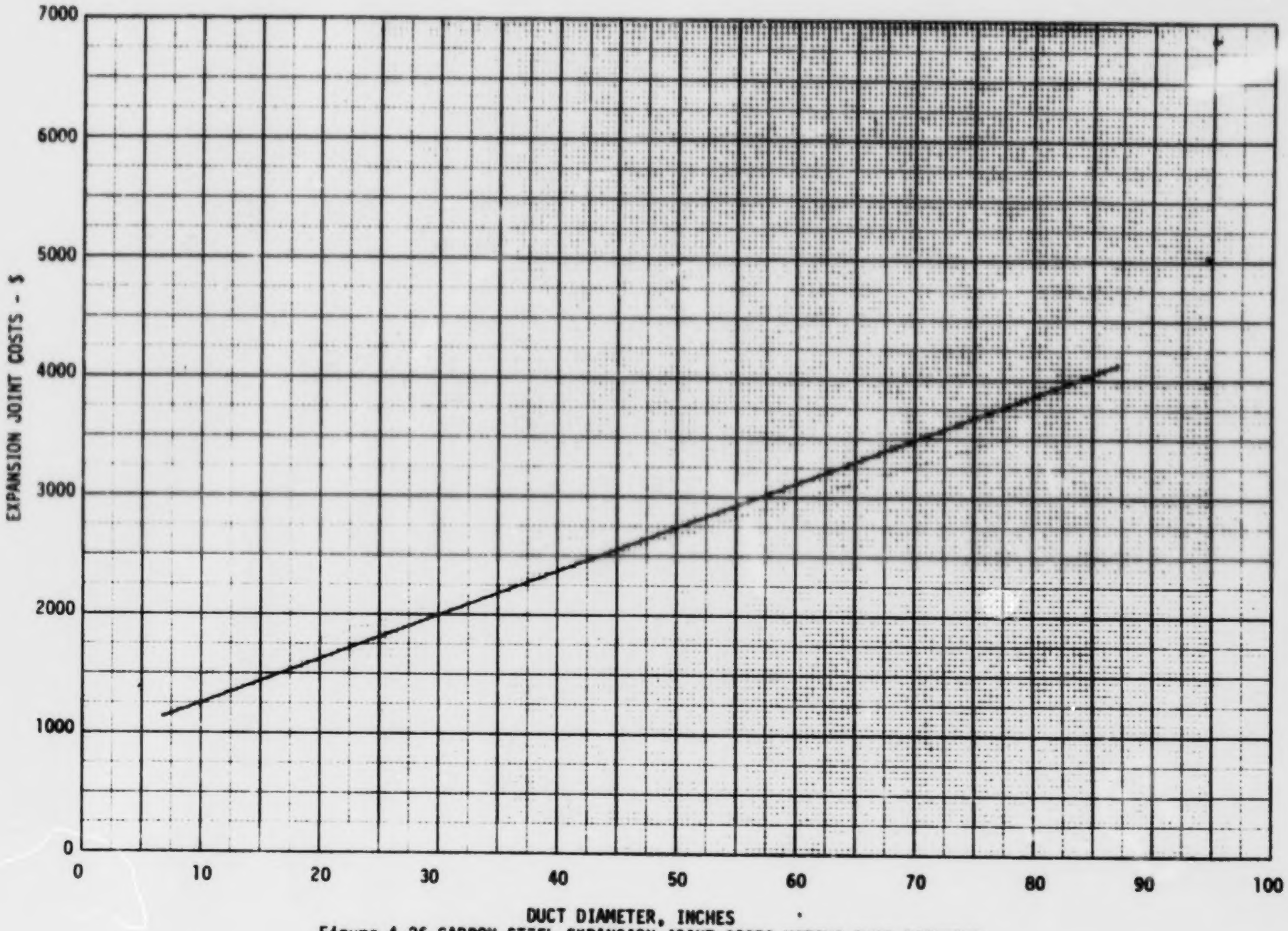


Figure 4-26 CARBON STEEL EXPANSION JOINT COSTS VERSUS DUCT DIAMETER

4.6.5 Refractory Materials

Table 4-3 contains pricing data for refractory materials. Refractory may be applied to capture hoods, straight duct, elbows, tees, transitions, spray chambers, thermal and catalytic incinerators (for replacement), and stacks. To estimate the cost, determine the surface area to be lined, the thickness of the lining, and the type of refractory to be used. Compute the cubic feet of refractory required and multiply by the price.

Table 4-3

REFRACTORY ESTIMATING COSTS, DATA VALID FOR DECEMBER 1975

TYPE	APPLICATION/FORM	DENSITY (Lb/cu. ft.)	PURCHASE PRICE ($/cu. ft.)	INSTALLED COST ($/cu. ft.)
Insulating Firebrick, 2300 °F	Brick	50	N/A	N/A
High Duty Firebrick, 3100 °F	Brick	135	N/A	N/A
Super Duty Firebrick, 3200 °F	Brick	145	$6	$75
Insulating Castable, 2000 °F	Cast in Forms, Trowelled, or Gunned	50	$5	$25
General Purpose Castable, 2200 °F	"	120	N/A	N/A
Dense Castable, 3000 °F	"	140	$20	$65
Plastic, 3000 °F	Rammed w/Pneumatic Hammer	140	$11	N/A
Ceramic Fibre Matt, 2300 °F	Like Mineral Wool	N/A	N/A	$20
Ceramic Fibre Board, 1800 °F	Rigid Board	N/A	N/A	N/A
High Alumina, 3500 °F	Brick	180	N/A	N/A

N/A = Not Available

Ref: Appendix C, Source No. 37,"Afterburner Systems Study"
Chapter 7, pp 100-110.

4.7 DAMPERS

Prices for rectangular and circular dampers, with and without automatic temperature regulated controls, are contained in Figures 4-27 and 4-28, respectively. Rectangular dampers are priced as a function of cross-sectional area for a length-to-width ratio of 1.3. Circular dampers are priced as a function of damper diameter. These prices are for dampers only - the type that may be used inside a duct or at inlets and outlets of control equipment components.

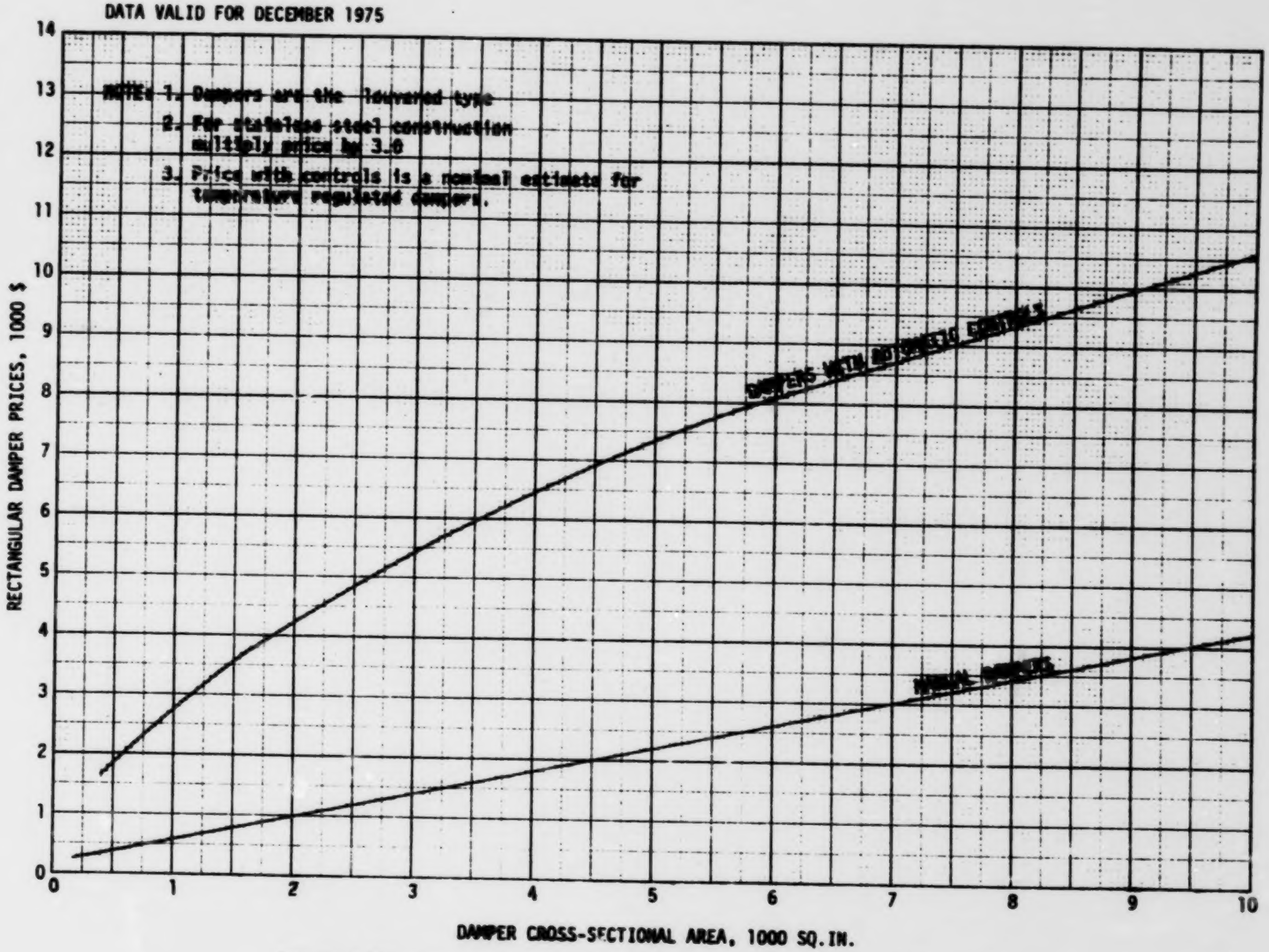


Figure.4-27 CARBON STEEL RECTANGULAR DAMPER PRICES VS. AREA FOR L/W=1.3

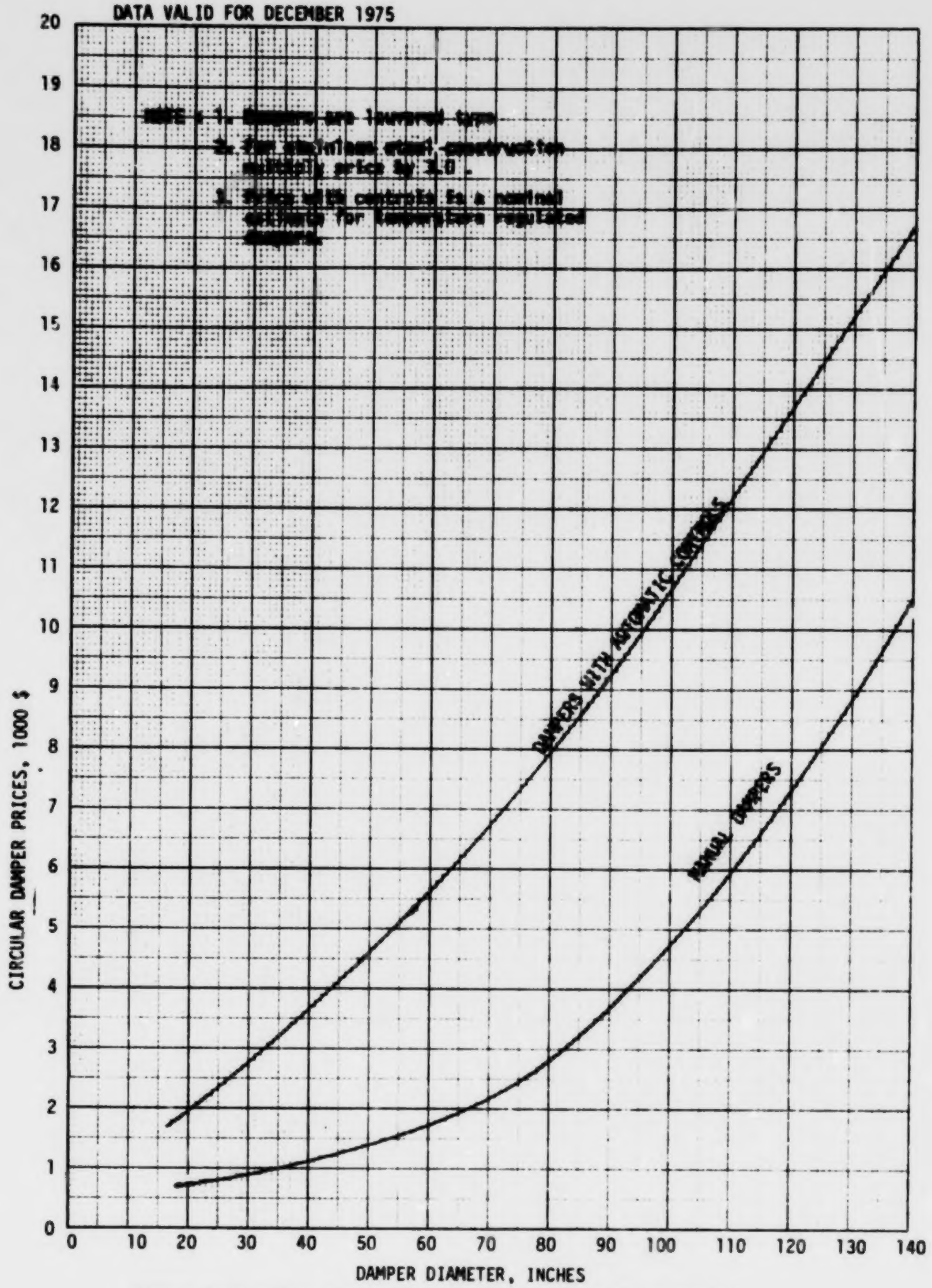
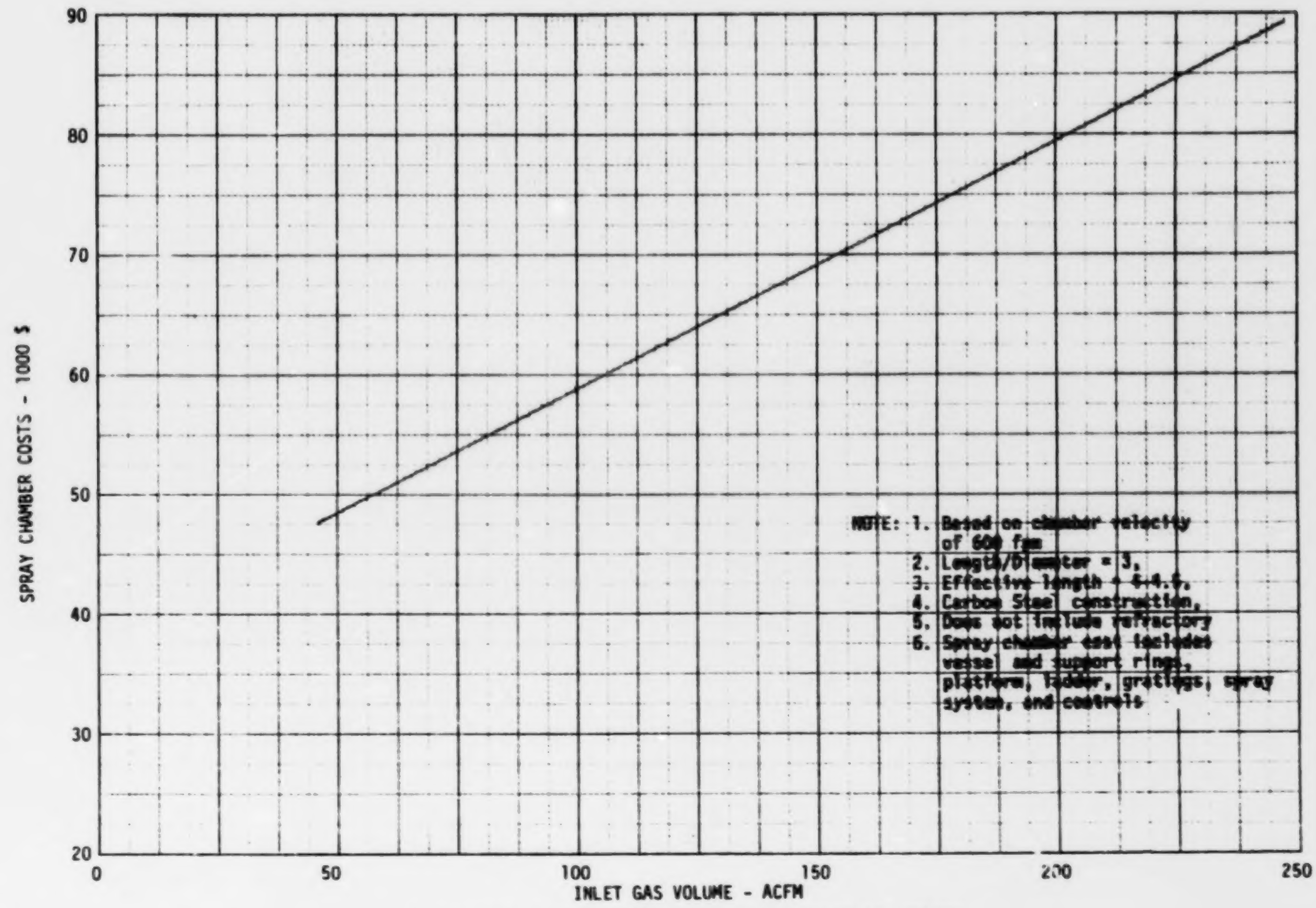


Figure 4-28 CARBON STEEL CIRCULAR DAMPER PRICES VS. DIAMETER

4.8 HEAT EXCHANGERS

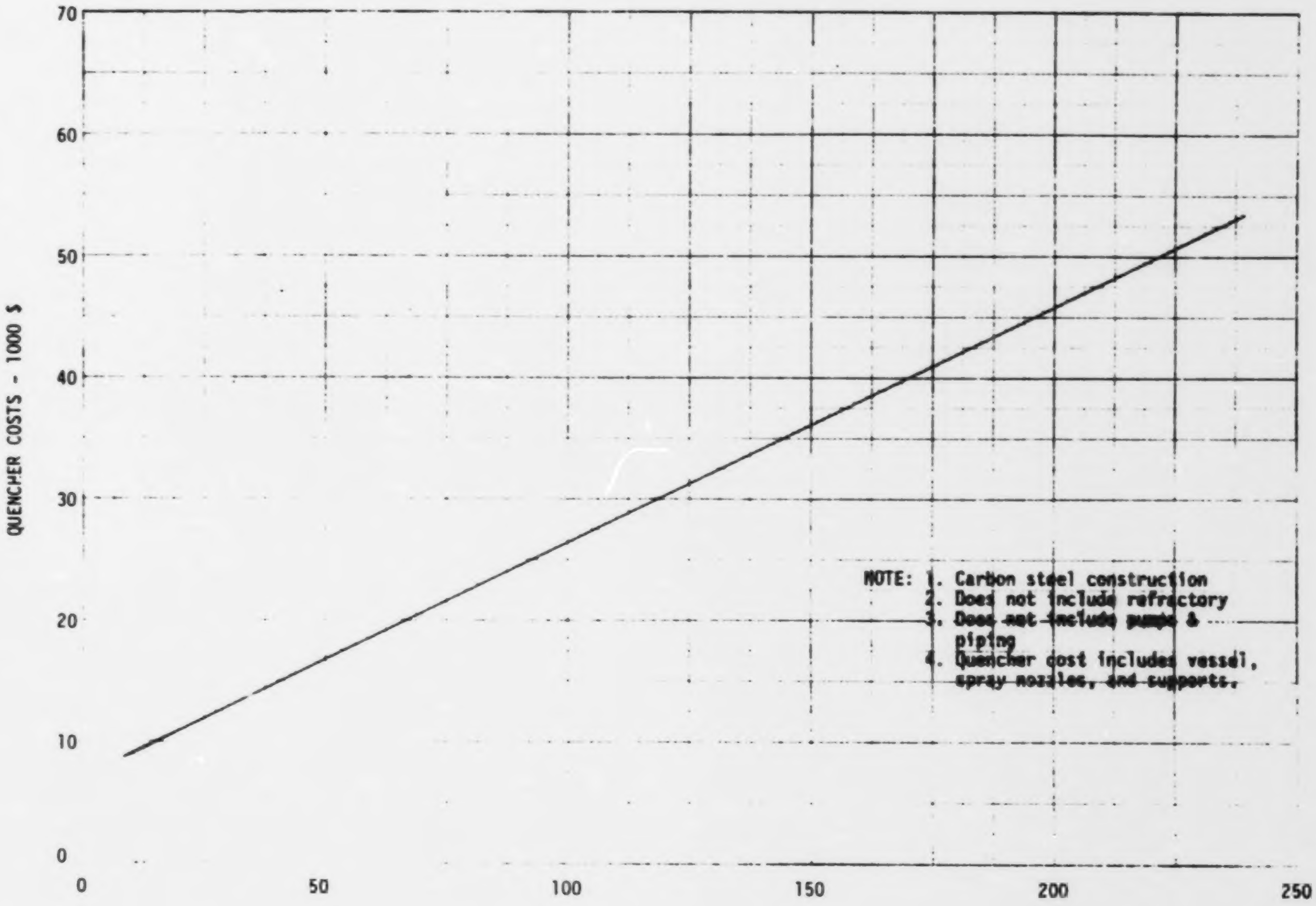
4.8.1 Spray Chambers and Quenchers

Figure 4-29 contains prices for spray chambers and Figure 4-30 gives prices for quenchers, both versus inlet gas volume.



NOTE:
1. Based on chamber velocity of 600 fpm
2. Length/Diameter = 3,
3. Effective length = 4-4.5,
4. Carbon Steel construction,
5. Does not include refractory
6. Spray chamber cost includes vessel and support rings, platform, ladder, gratings, spray system, and controls

Figure 4-29 SPRAY CHAMBER COSTS VERSUS INLET GAS VOLUME



NOTE:
1. Carbon steel construction
2. Does not include refractory
3. Does not include pumps & piping
4. Quencher cost includes vessel, spray nozzles, and supports.

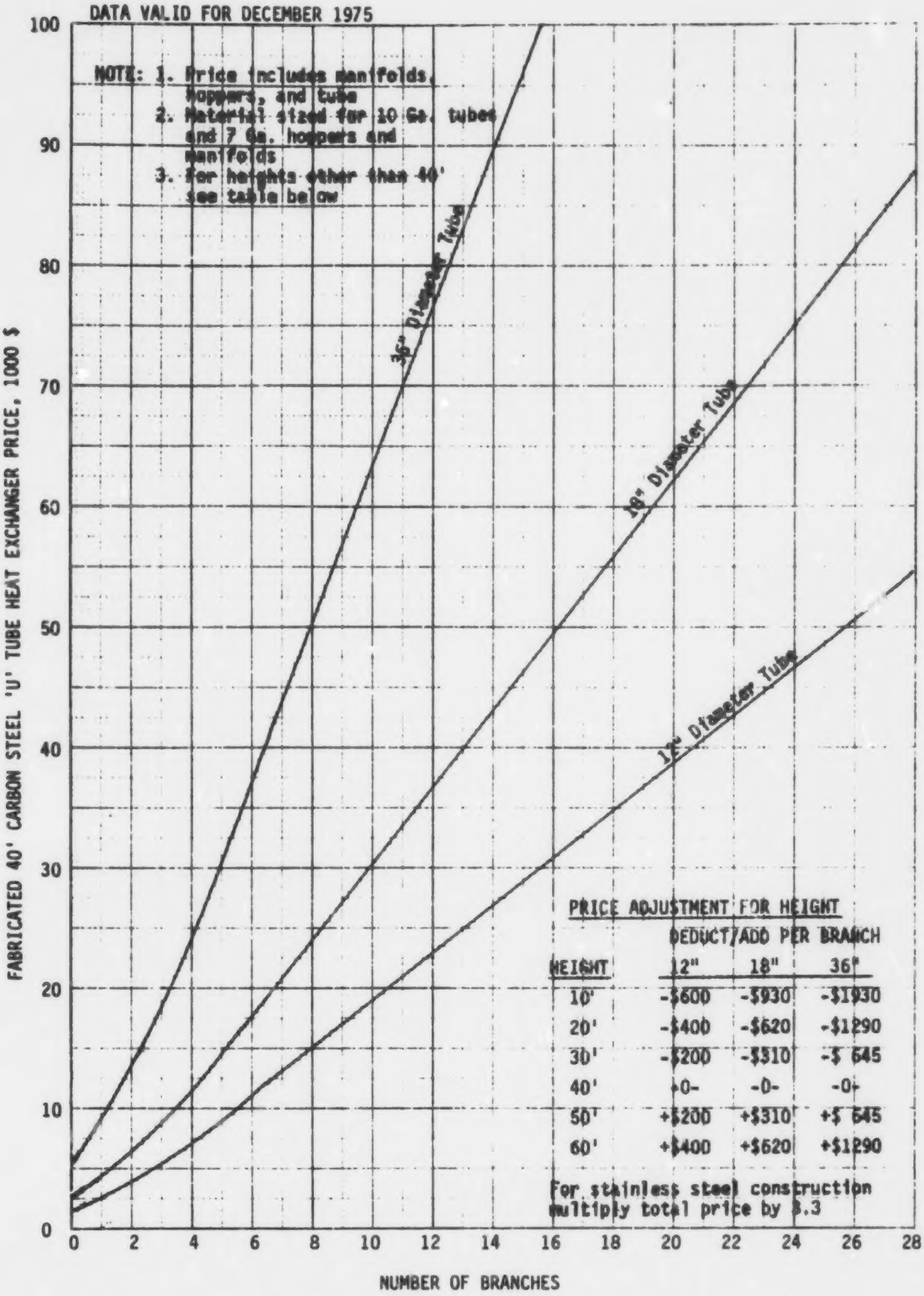
Figure 4-30 QUENCHER COSTS VERSUS INLET GAS VOLUME

4.8.2 Radiant Coolers

Figure 4-31 contains prices for 'U' tube radiant coolers as a function of the number of branches ('U' tubes), the diameter of the tube, and the height of the tube. Refer to Appendix C, Source No. 88, for design of 'U' tubes.

4.8.3 Dilution Air Ports

Figure 4-32 contains prices for dilution air ports as a function of port diameter and plate thickness.



DATA VALID FOR DECEMBER 1975

NOTE:
1. Price includes manifolds, hoppers, and tube
2. Material sized for 10 Ga. tubes and 7 Ga. hoppers and manifolds
3. For heights other than 40' see table below

PRICE ADJUSTMENT FOR HEIGHT

	DEDUCT/ADD PER BRANCH		
HEIGHT	12"	18"	36"
10'	-$600	-$930	-$1930
20'	-$400	-$620	-$1290
30'	-$200	-$310	-$ 645
40'	-0-	-0-	-0-
50'	+$200	+$310	+$ 645
60'	+$400	+$620	+$1290

For stainless steel construction multiply total price by 3.3

FIGURE 4-31 FABRICATED 40 FOOT HIGH 'U' TUBE HEAT EXCHANGER PRICES WITH HOPPERS AND MANIFOLDS

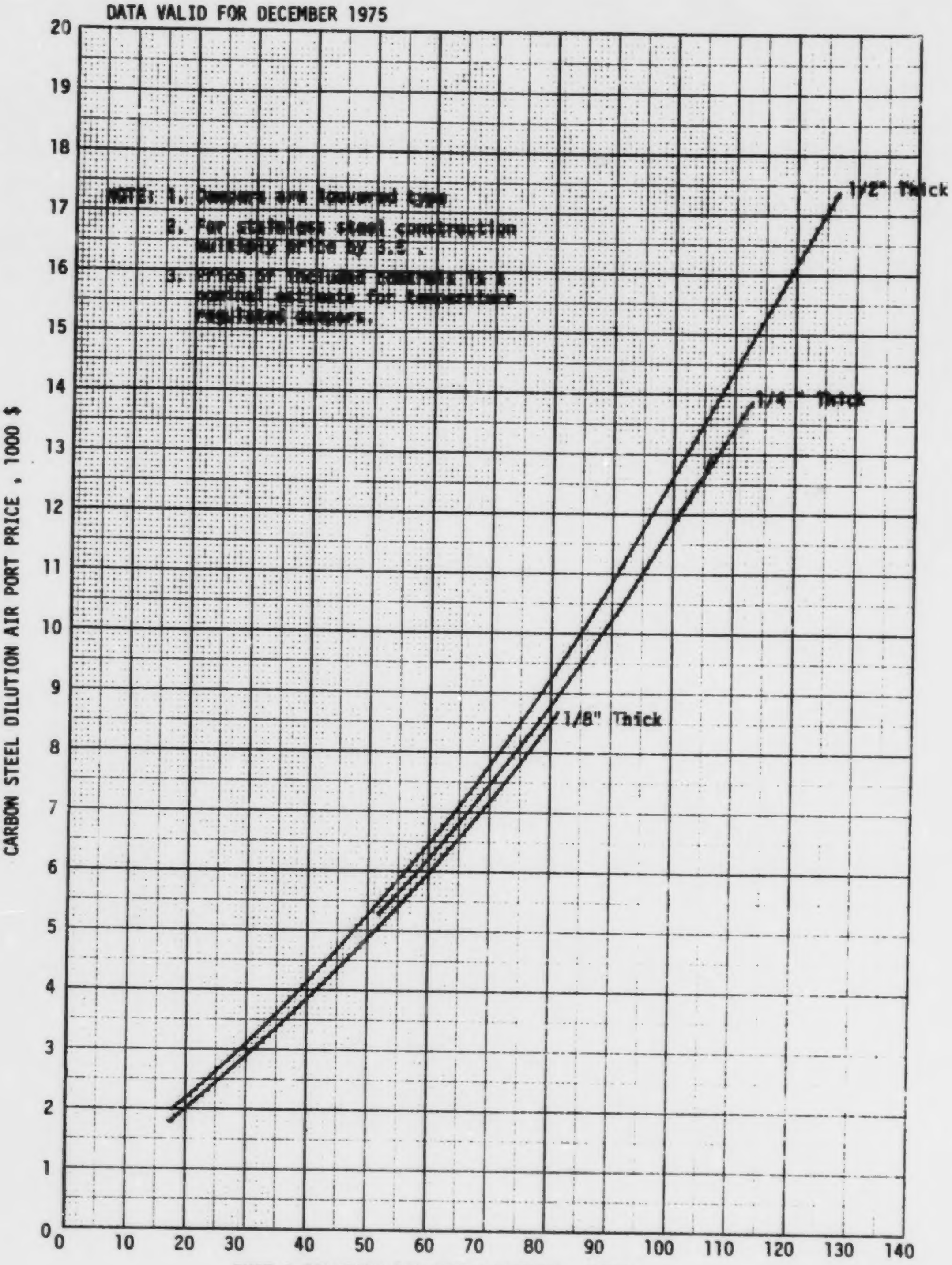


Figure 4-32 PRICES FOR FABRICATED CARBON STEEL DILUTION AIR PORTS VS. DIAMETER AND PLATE THICKNESS

4.9 MECHANICAL COLLECTORS

Figure 4-33 provides a means of estimating the volume capacity of mechanical collectors as a function of inlet cross-sectional area. Figure 4-34 provides a means of estimating the critical particle size for collectors vs. inlet area. Critical particle size is defined as the largest sized particle not separated from the gas stream.

Figures 4-35 through 4-39 contain pricing data for mechanical collectors and components as a function of inlet area.

For example, suppose 50,000 cfm is to be passed through a mechanical collector prior to entering a baghouse. A pair of 25,000 cfm capacity collectors with a pressure drop of 4" ΔP and an inlet area of 9½ sq. ft. would be satisfactory for the purpose. The critical particle size is found to be 28 microns. For 10 Ga. carbon steel construction, the price of the collector would be about $4500. The cost of additional components would be:

support:	$2700
hopper:	780
scroll:	1400
	$4880

The total price is thus $4880 + $4500 = $9380. In general, price of collectors varies directly with inlet area since the mass of the unit increases with increasing area. However, these curves give prices for only single-unit collectors, not multiple units.

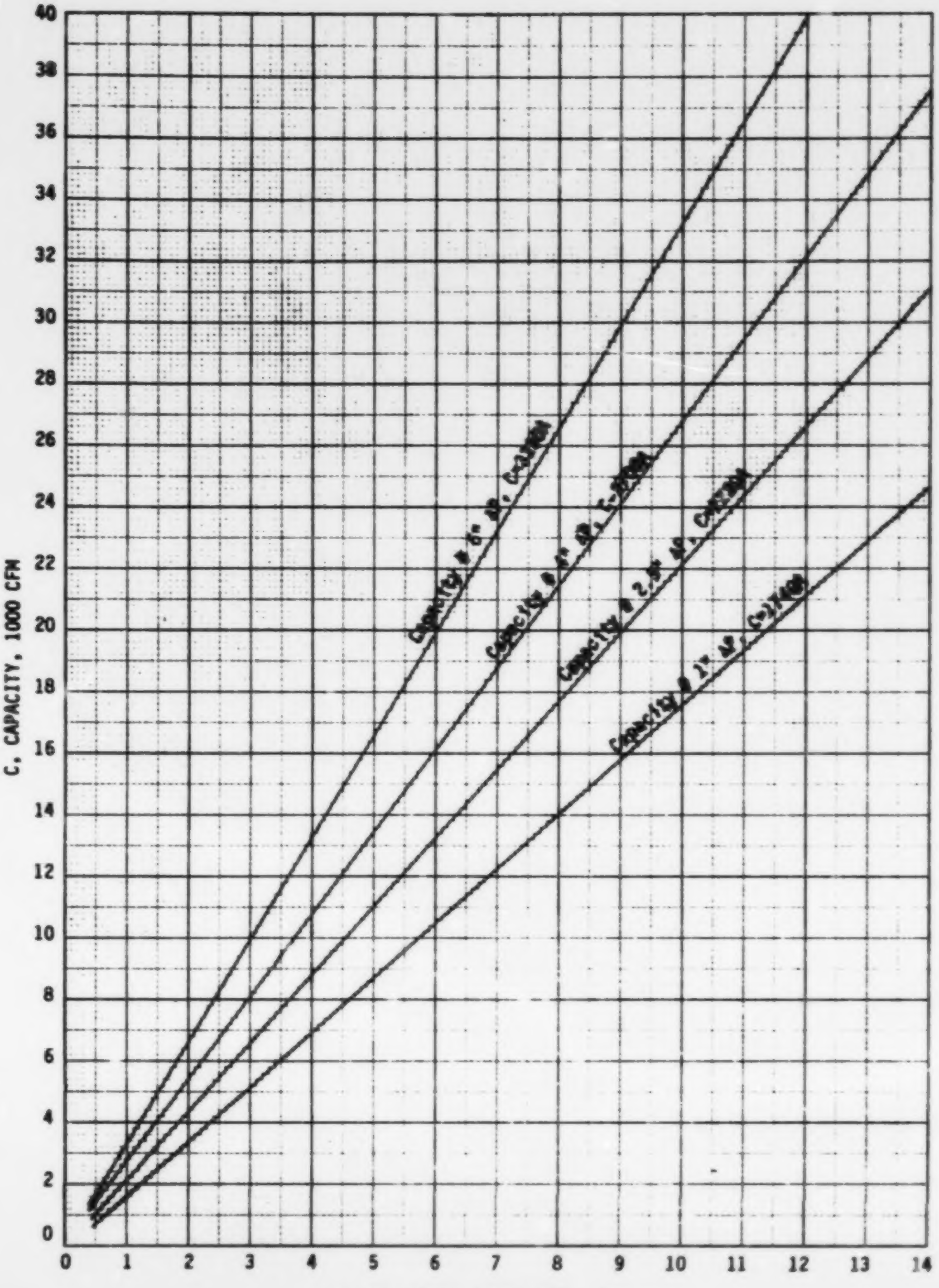


Figure 4-33 CAPACITY ESTIMATES FOR MECHANICAL COLLECTORS

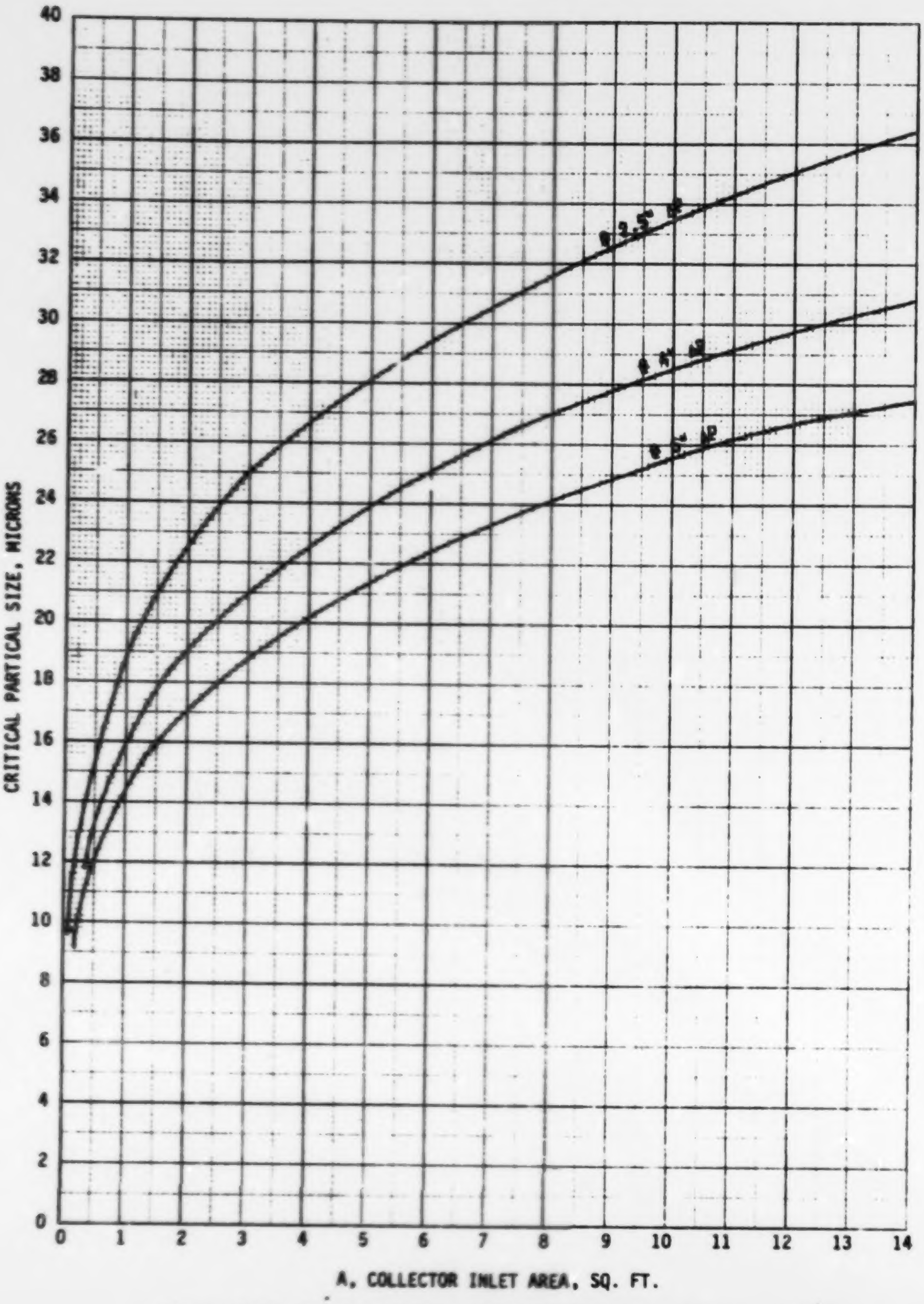
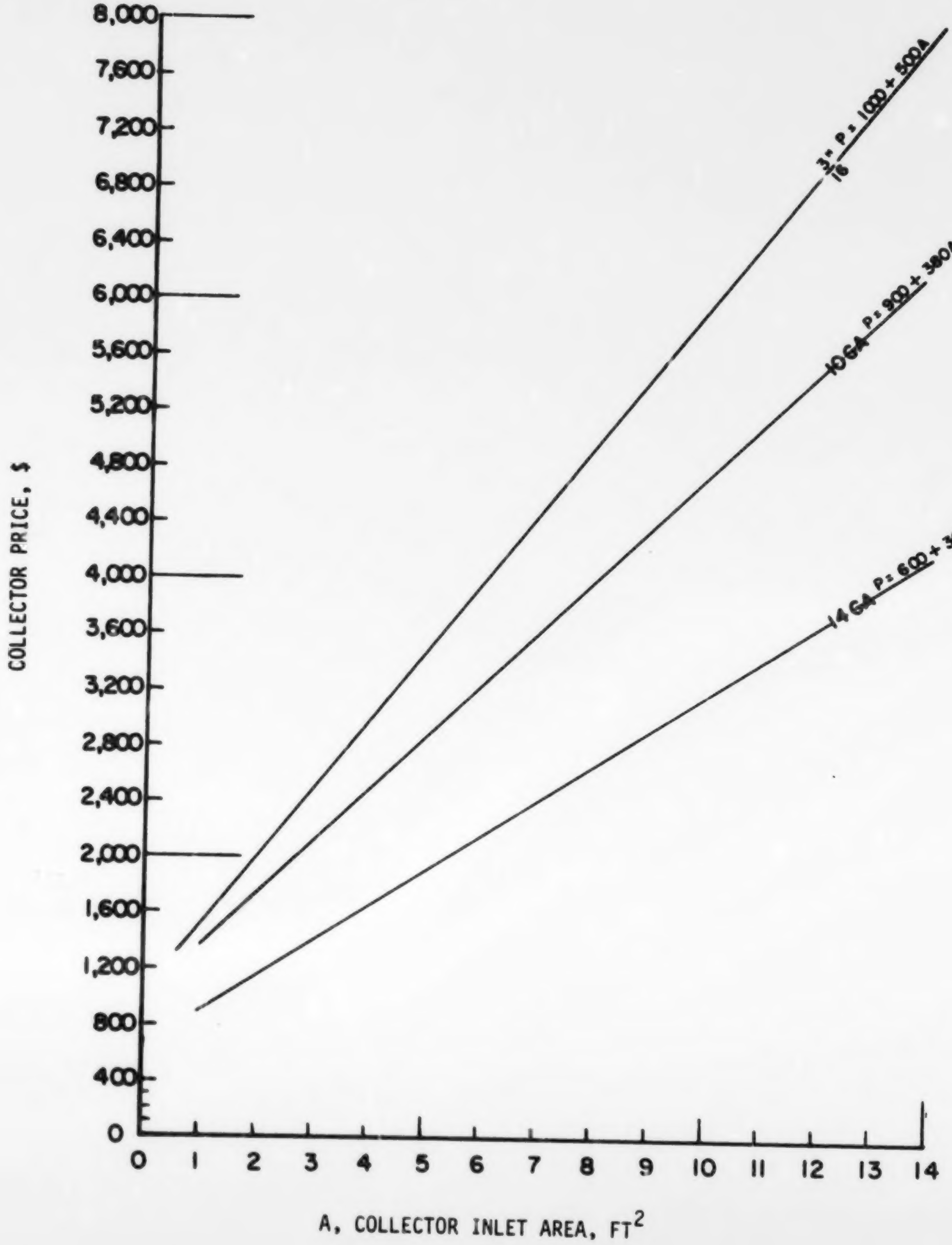


Figure 4-34 CRITICAL PARTIAL SIZE ESTIMATES FOR MECHANICAL COLLECTORS



DATA VALID FOR DECEMBER 1975

Figure 4-35 MECHANICAL COLLECTOR PRICES FOR CARBON STEEL CONSTRUCTION VS. INLET AREA

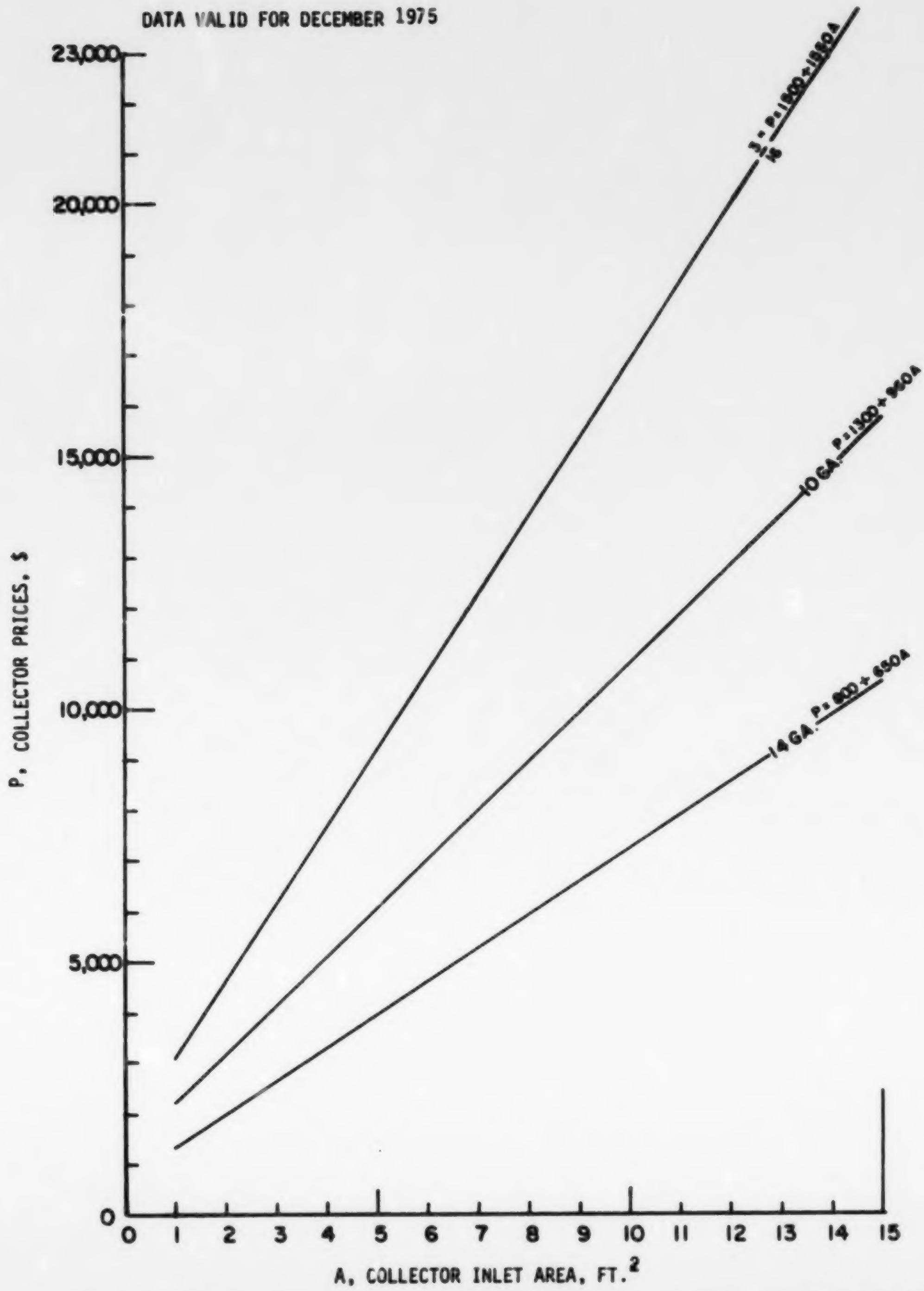
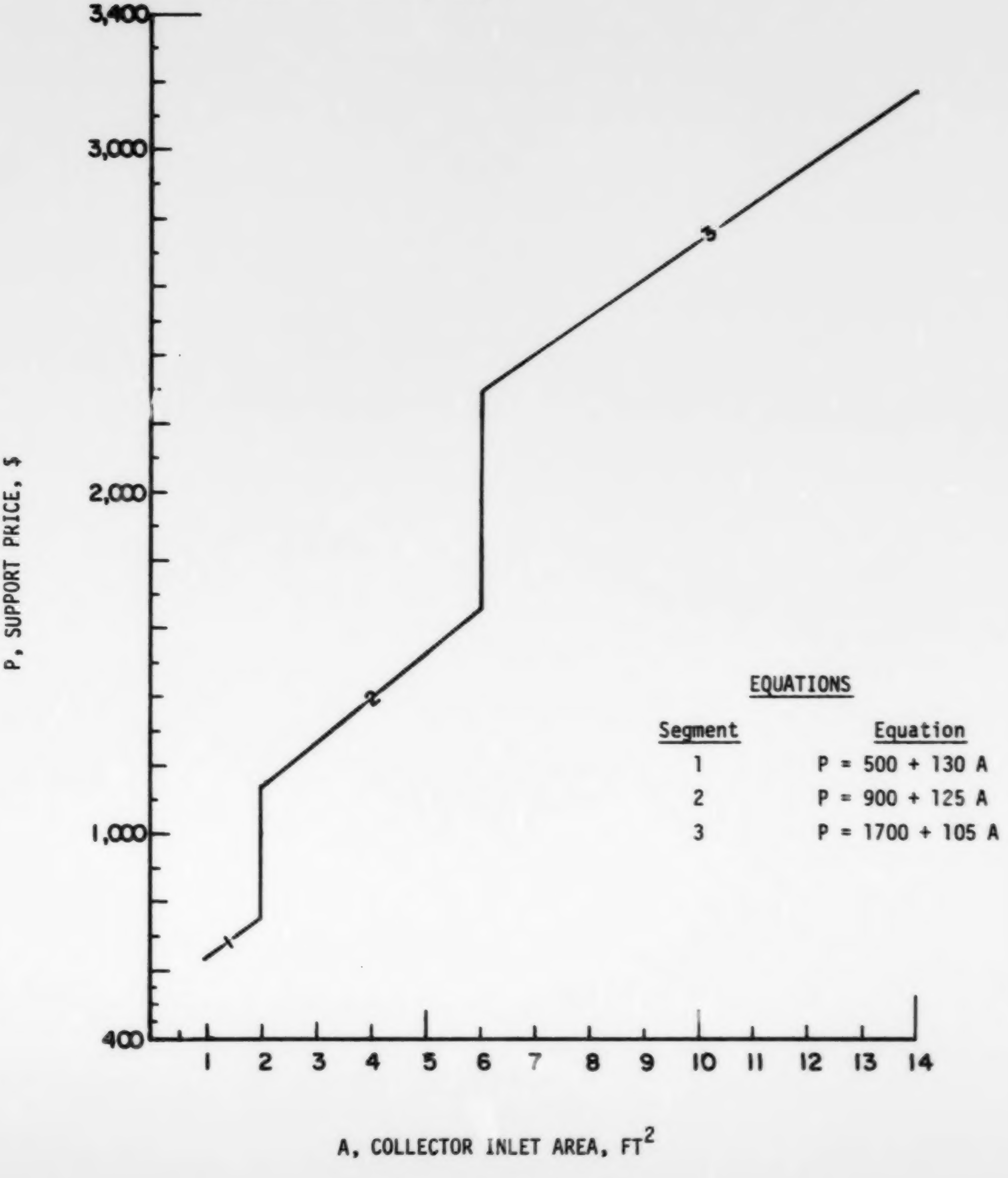


Figure 4-36 MECHANICAL COLLECTOR PRICES FOR STAINLESS STEEL CONSTRUCTION VS. INLET AREA



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EQUATIONS

Segment	Equation
1	$P = 500 + 130\ A$
2	$P = 900 + 125\ A$
3	$P = 1700 + 105\ A$

Figure 4-37 MECHANICAL COLLECTOR SUPPORT PRICES VS. COLLECTOR INLET AREA

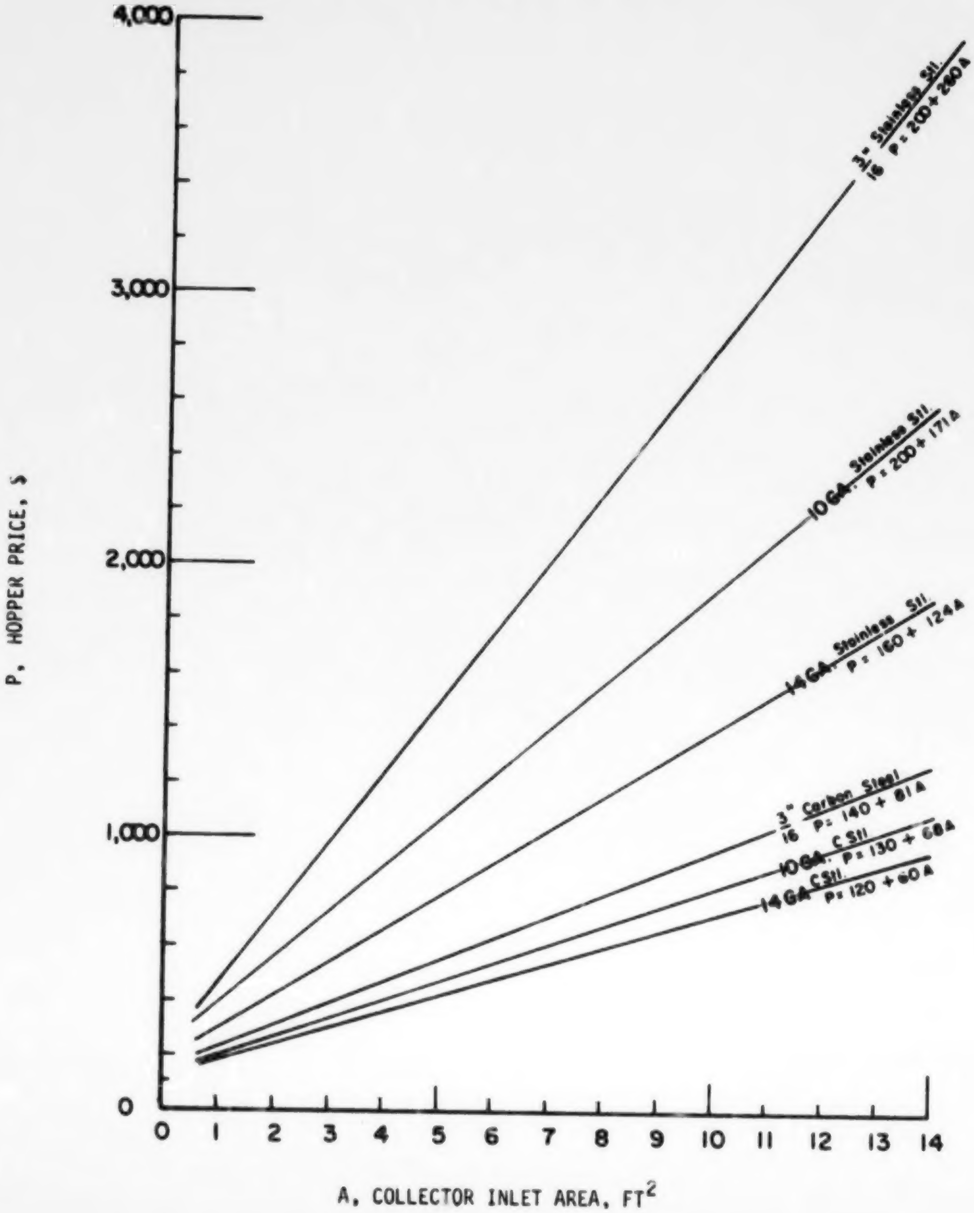

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Figure 4-38 MECHANICAL COLLECTOR DUST HOPPER PRICES FOR CARBON AND STAINLESS STEEL CONSTRUCTION VS. COLLECTOR INLET AREA

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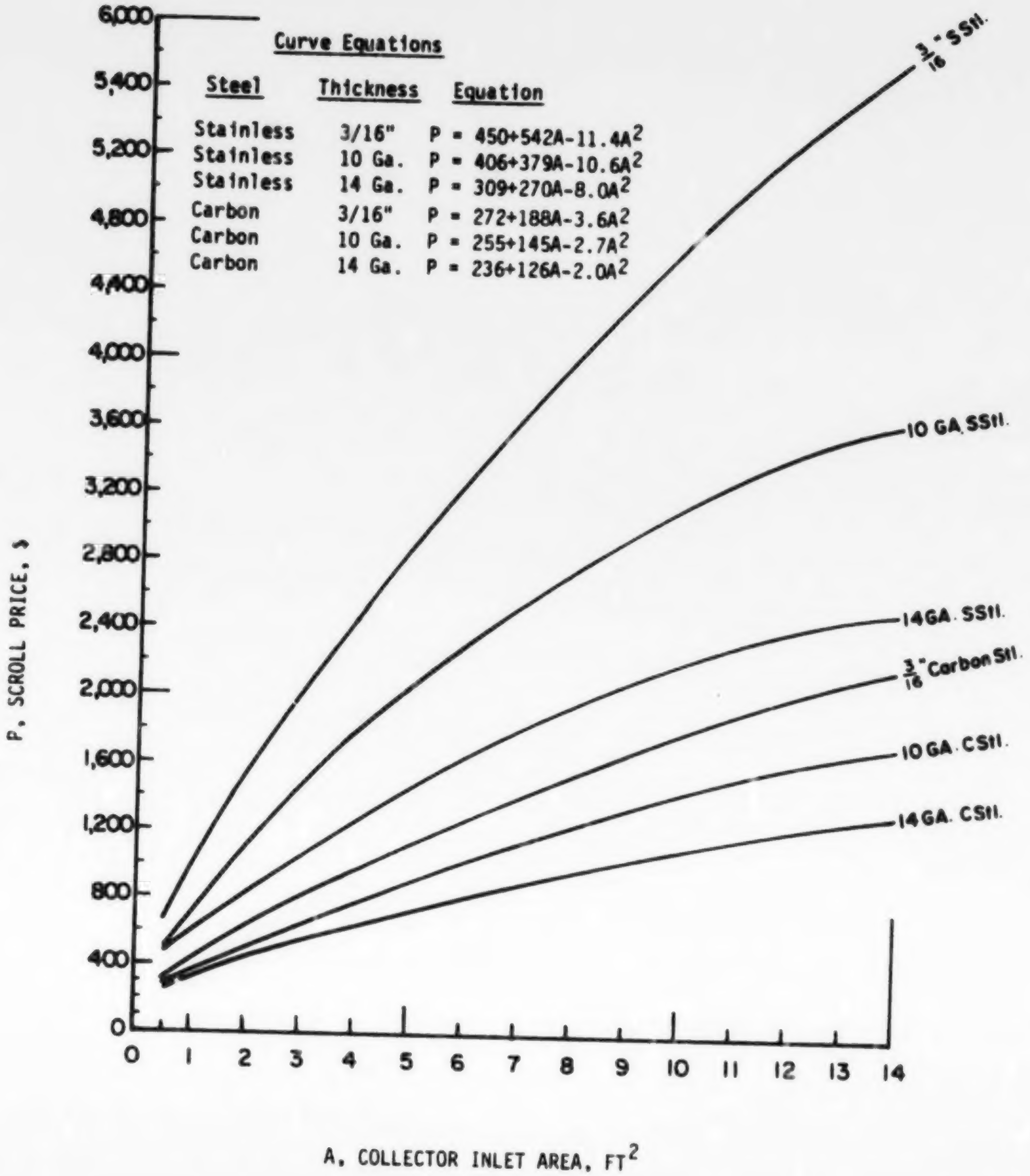

Curve Equations

Steel	Thickness	Equation
Stainless	3/16"	$P = 450+542A-11.4A^2$
Stainless	10 Ga.	$P = 406+379A-10.6A^2$
Stainless	14 Ga.	$P = 309+270A-8.0A^2$
Carbon	3/16"	$P = 272+188A-3.6A^2$
Carbon	10 Ga.	$P = 255+145A-2.7A^2$
Carbon	14 Ga.	$P = 236+126A-2.0A^2$

Figure 4-39 MECHANICAL COLLECTOR SCROLL OUTLET PRICES FOR CARBON AND STAINLESS STEEL CONSTRUCTION VS. COLLECTOR INLET AREA

4.10 FANS, MOTORS, AND STARTERS

4.10.1 Backwardly Curved Fans

Backwardly curved fans are priced as a function of the actual air flow rate, pressure drop at standard conditions, and class, as given in Figure 4-40. If, for example, a Class III fan is to operate at sea level with gas temperature of 70 F and is to handle a gas volume of 20,000 CFM at 10" of water, the price would be $3400.

However, in many cases a fan would not be operated at standard conditions, and adjustments must be made through the use of Table 4-8 to properly cost the fan. For example, if actual conditions are:

a. gas temperature = 300F
b. altitude = 1000 ft.
c. actual cfm = 50000
d. actual ΔP = 10" static pressure

then the fan is priced as follows:

1. obtain fan sizing factor from Table 4-8 for 300F at 1000 ft = .672
2. actual 10" static pressure/.672 = 15" at standard conditions
3. enter Figure 4-40 with 50,000 cfm and 15", read price of $6800 for Class IV fan. Since this is a high heat application, the estimated price is $6400 X 1.03 = $7000.

The prices for the motor and the starter are obtained from Figure 4-41. Enter the chart on the right with the gas flow rate and the static pressure at standard conditions. For 10" S.P. and 20,000 cfm, find the point with those coordinates and draw lines parallel to the "FAN RPM" guidelines and the "BHP" guidelines. Read the fan rpm on the scale to the right, read the bhp on the scale to the left. Then read the price for the type of starter needed and for the drip-proof motor at the selected rpm. A guide to determining motor rpm is given in Table 4-7. For the example, the fan rpm is found to be about 1600 and the motor bhp is 44. According to Table 4-7, the motor rpm should be 1800, hence the corresponding price is about $600.

If a magnetic starter is selected, the price is about \$350. Prices for motor types other than drip-proof may be estimated using Table 4-4. A totally enclosed motor for this example would cost \$600 X 1.5 = \$900. The selection of a motor type may be made from Table 4-6.

For conditions other than standard, the following steps must be taken to establish the motor and starter price. Again consider the 300F application from before.

1. Find the bhp from Figure 4-41 using 50000 cfm and 15" S.P. = 180 bhp
2. Correct the bhp by multiplying by the fan sizing factor: 180 bhp X 0.672 = 121 bhp, actual.
3. Find motor and starter prices at 121 bhp. The fan rpm does not require adjustment.

An inlet or outlet damper is usually required on fans, and prices for such are presented in Figure 4-44. Note that the static pressure is measured for standard conditions, as in Figures 4-40 and 4-41.

V-belt drives may be selected for some applications. Figure 4-45 contains prices for V-belt drives as a function of motor bhp and fan rpm. For direct drives, estimate price at 5% of the motor price.

4.10.2 Radial Tip Fans

The method of estimating prices for radial tip fans is the same as for backwardly curved fans. Prices for radial tip fans operating under 20" S.P. are given in Figure 4-42. Figure 4-43 provides the data for determining the fan rpm and motor bhp for radial tip fans. Refer to Figure 4-41 and Table 4-4 to obtain the motor and starter prices once the bhp has been determined.

For radial tip fan applications involving greater that 20" S.P., Figures 4-46 and 4-47 should be used to estimate the fan and motor prices respectively. The static pressure must be converted to standard conditions as before, using Table 4-8.

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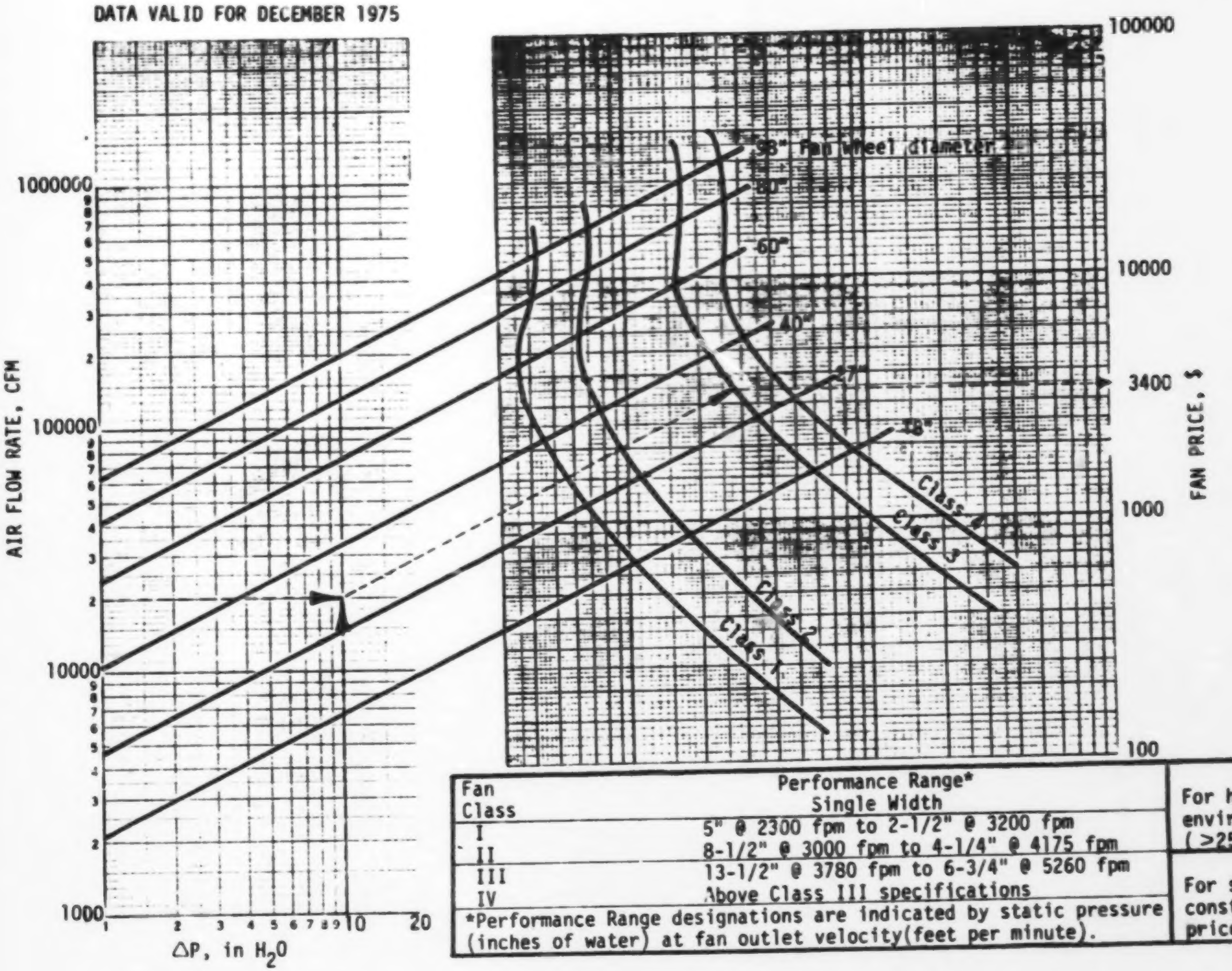

(AT STANDARD CONDITIONS)

Fan Class	Performance Range* Single Width	
I	5" @ 2300 fpm to 2-1/2" @ 3200 fpm	For high temperature environment add 3% (>250°F, < 600°F)
II	8-1/2" @ 3000 fpm to 4-1/4" @ 4175 fpm	
III	13-1/2" @ 3780 fpm to 6-3/4" @ 5260 fpm	For stainless steel construction multiply price by 2.5 .
IV	Above Class III specifications	

*Performance Range designations are indicated by static pressure (inches of water) at fan outlet velocity(feet per minute).

Figure 4-40 BACKWARDLY CURVED FAN PRICES VERSUS CLASS, CFM, AND ΔP FOR ARRANGEMENT NO. 1

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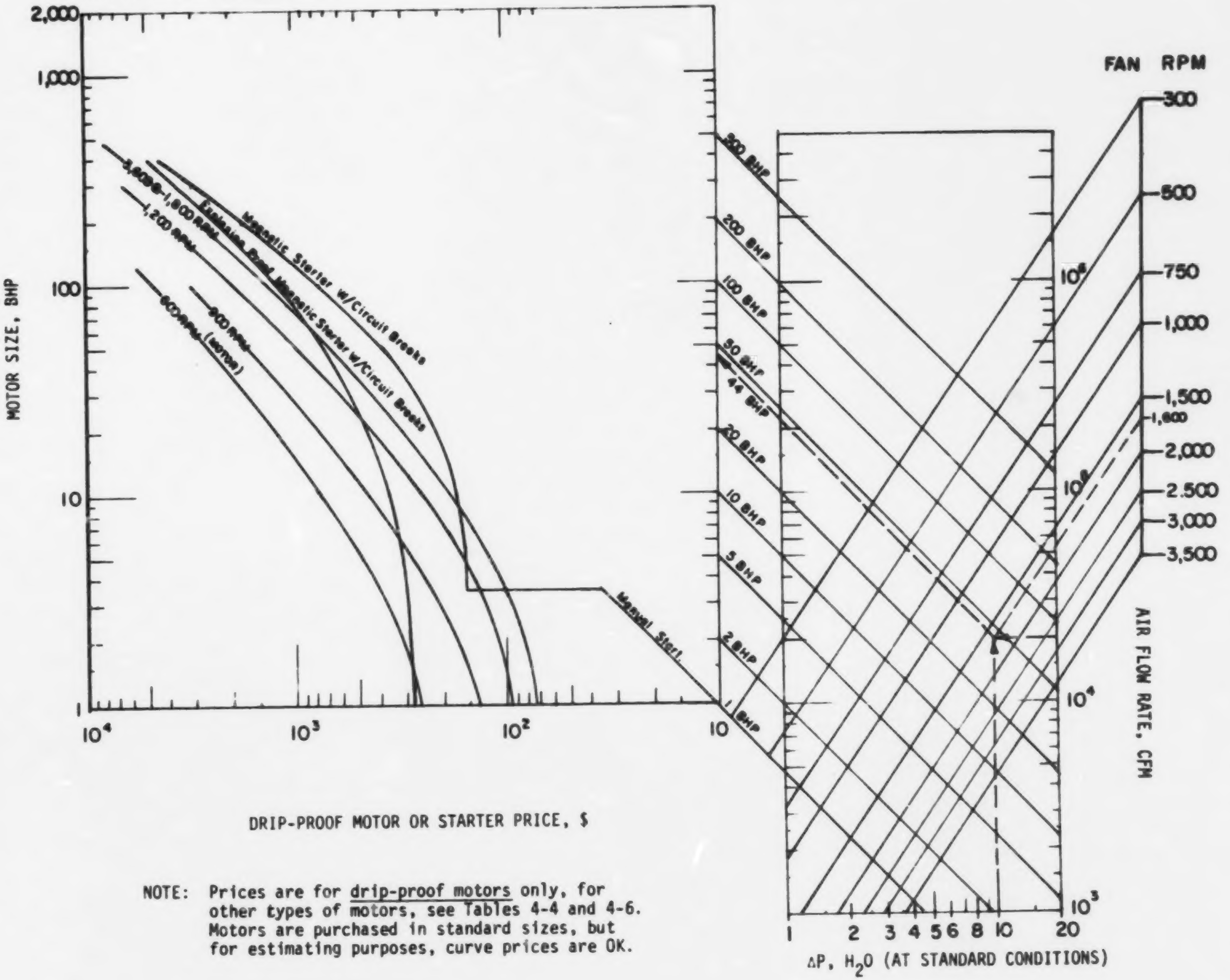


DRIP-PROOF MOTOR OR STARTER PRICE, $

NOTE: Prices are for drip-proof motors only, for other types of motors, see Tables 4-4 and 4-6. Motors are purchased in standard sizes, but for estimating purposes, curve prices are OK.

Figure 4-41 BHP, FAN RPM AND MOTOR AND STARTER PRICES VS. ΔP AND CFM.

Table 4-4

PRICING FACTORS FOR OTHER MOTOR TYPES *

HORSEPOWER	TOTALLY ENCLOSED FAN COOLED	EXPLOSION PROOF
≤ 20	1.3	1.6
> 20	1.5	1.7

Table 4-5

MOTOR AND STARTER PRICE EQUATIONS

RPM	EQUATION
3600 1800	$P = 60+11.9\ BHP + 0.00845 BHP^2$
1200	$P = 68+18.0\ BHP$
900	$P = 100+35.0\ BHP-0.07\ BHP^2$
600	$P = 204+52.6\ BHP-0.083\ BHP^2$
Mag. Starter	$P = 150+2.5\ BHP+.04\ BHP^2 - .00005\ BHP^3$
Exp. Prf. Str.	$P = 270+8.5\ BHP+.008\ BHP^2$

Table 4-6

MOTOR TYPE SELECTION

Drip-proof: In non-hazardous, reasonably clean surroundings free of any abrasive or conducting dust and chemical fumes. Moderate amounts of moisture or dust and falling particles or liquids can be tolerated. Totally Enclosed Non-Ventilated or Fan Cooled: In non-hazardous atmospheres containing abrasive or conducting dusts, high concentrations of chemical or oil vapors and/or where hosing down or severe splashing is encountered.	Totally Enclosed Explosion Proof: Use in hazardous atmospheres containing: Class I, Group D, acetone, acrylonitrile, alcohol, ammonia, benzine, benzol, butane ethylene dichloride, gasoline, hexane, lacquer solvent vapors, naptha, natural gas, propane, propylene, styrene, vinyl acetate, vinyl chloride or xylenes; Class II, Group G, flour, starch or grain dust; Class II, Group F, carbon black, coal or coke dust; Class II, Group E, metal dust including magnesium and aluminum or their commercial alloys.

Table 4-7

MOTOR RPM SELECTION GUIDE

MOTOR RPM	FAN RPM RANGE
3600	2400 - 4000
1800	1400 - 2400
1200	1000 - 1400
900	700 - 1000
600	< 700

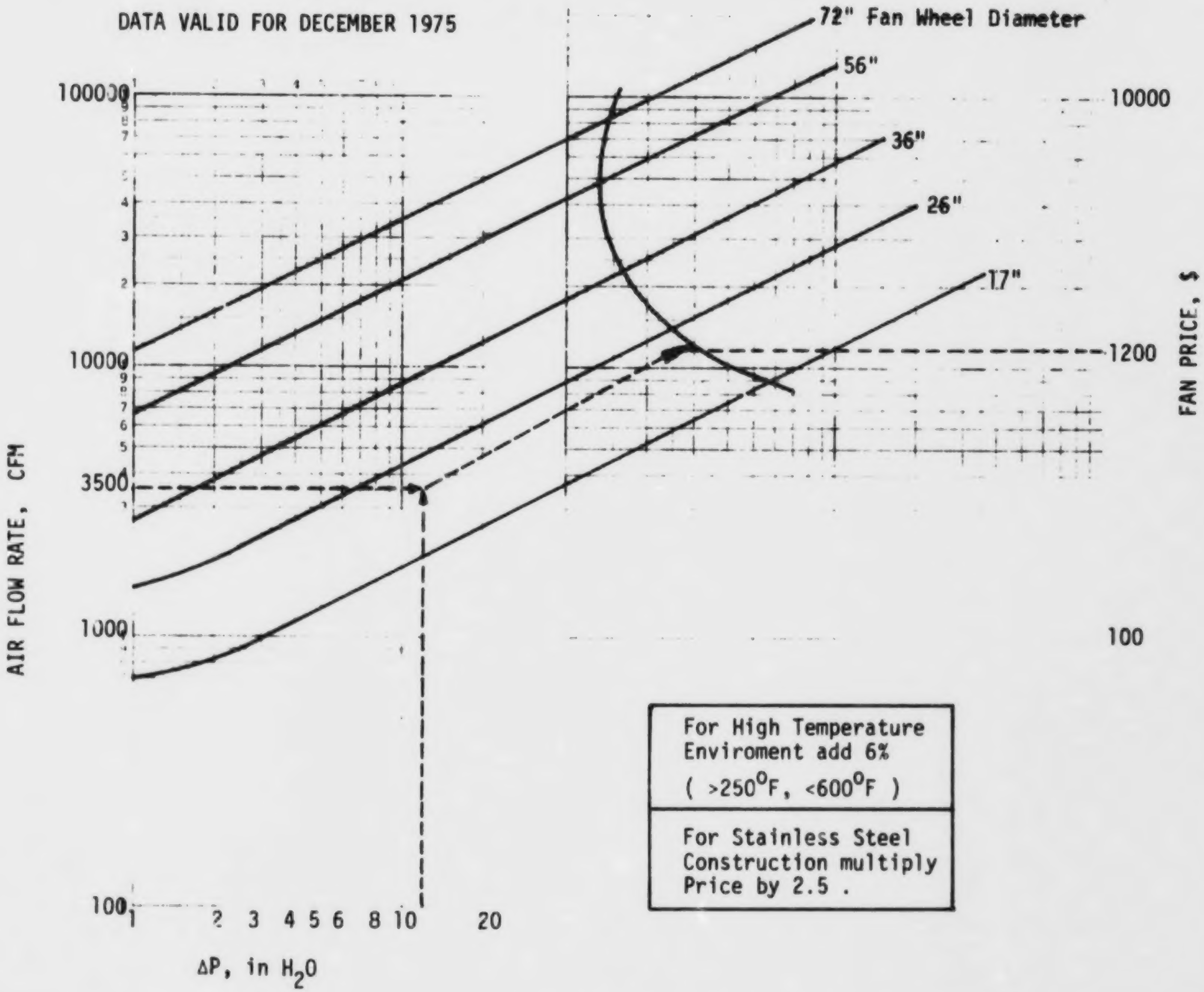
Table 4-8 FAN SIZING FACTORS: AIR DENSITY RATIOS

Unity Basis = Standard Air Density of .075 lb/ft^3

At sea level (29.92 in. Hg barometric pressure) this is equivalent to dry air at 70°F.

Air Temp. °F	Altitude in Feet Above Sea Level												
	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	15000	20000
	Barometric Pressure in Inches of Mercury												
	29.92	28.86	27.82	26.82	25.84	24.90	23.98	23.09	22.22	21.39	20.58	16.89	13.75
70	1.000	.964	.930	.896	.864	.832	.801	.772	.743	.714	.688	.564	.460
100	.946	.912	.880	.848	.818	.787	.758	.730	.703	.676	.651	.534	.435
150	.869	.838	.808	.770	.751	.723	.696	.671	.646	.620	.598	.490	.400
200	.803	.774	.747	.720	.694	.668	.643	.620	.596	.573	.552	.453	.369
250	.747	.720	.694	.669	.645	.622	.598	.576	.555	.533	.514	.421	.344
300	.697	.672	.648	.624	.604	.580	.558	.538	.518	.498	.480	.393	.321
350	.654	.631	.608	.586	.565	.544	.524	.505	.486	.467	.450	.369	.301
400	.616	.594	.573	.552	.532	.513	.493	.476	.458	.440	.424	.347	.283
450	.582	.561	.542	.522	.503	.484	.466	.449	.433	.416	.401	.328	.268
500	.552	.532	.513	.495	.477	.459	.442	.426	.410	.394	.380	.311	.254
550	.525	.506	.488	.470	.454	.437	.421	.405	.390	.375	.361	.296	.242
600	.500	.482	.465	.448	.432	.416	.400	.386	.372	.352	.344	.282	.230
650	.477	.460	.444	.427	.412	.397	.382	.368	.354	.341	.328	.269	.219
700	.457	.441	.425	.410	.395	.380	.366	.353	.340	.326	.315	.258	.210

SOURCE: AMCA STANDARD #402-66
AIR MOVING AND CONDITIONING ASSOCIATION, INC.
205 West Touhy Avenue
Park Ridge, Illinois 60068



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For High Temperature Enviroment add 6% (>250°F, <600°F)

For Stainless Steel Construction multiply Price by 2.5 .

Figure 4-42 RADIAL FAN PRICES VERSUS SCFM, AND ΔP FOR ARRANGEMENT NO. 1

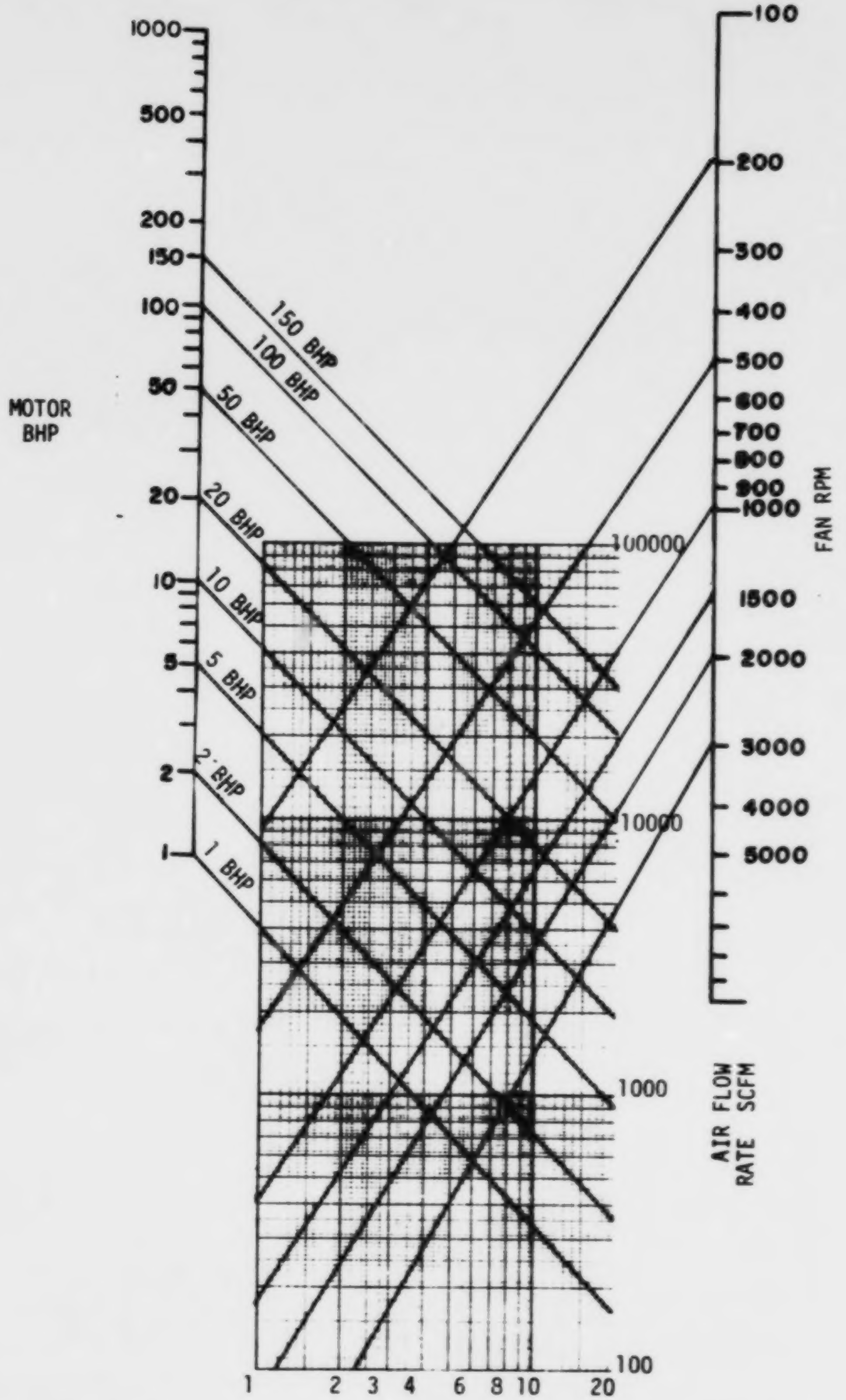

Figure 4-43 FAN RPM AND MOTOR BHP FOR RADIAL FANS

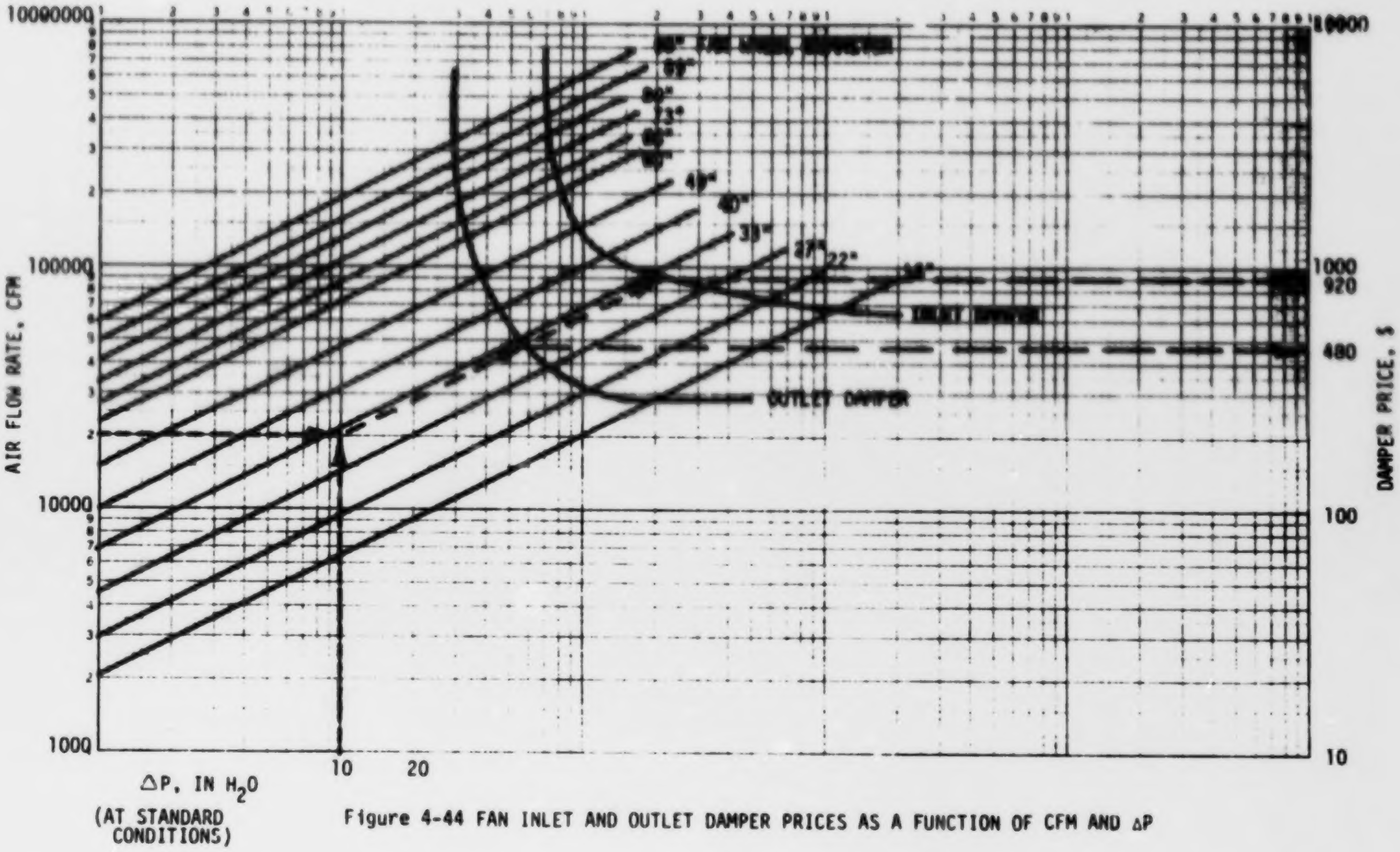

Figure 4-44 FAN INLET AND OUTLET DAMPER PRICES AS A FUNCTION OF CFM AND ΔP

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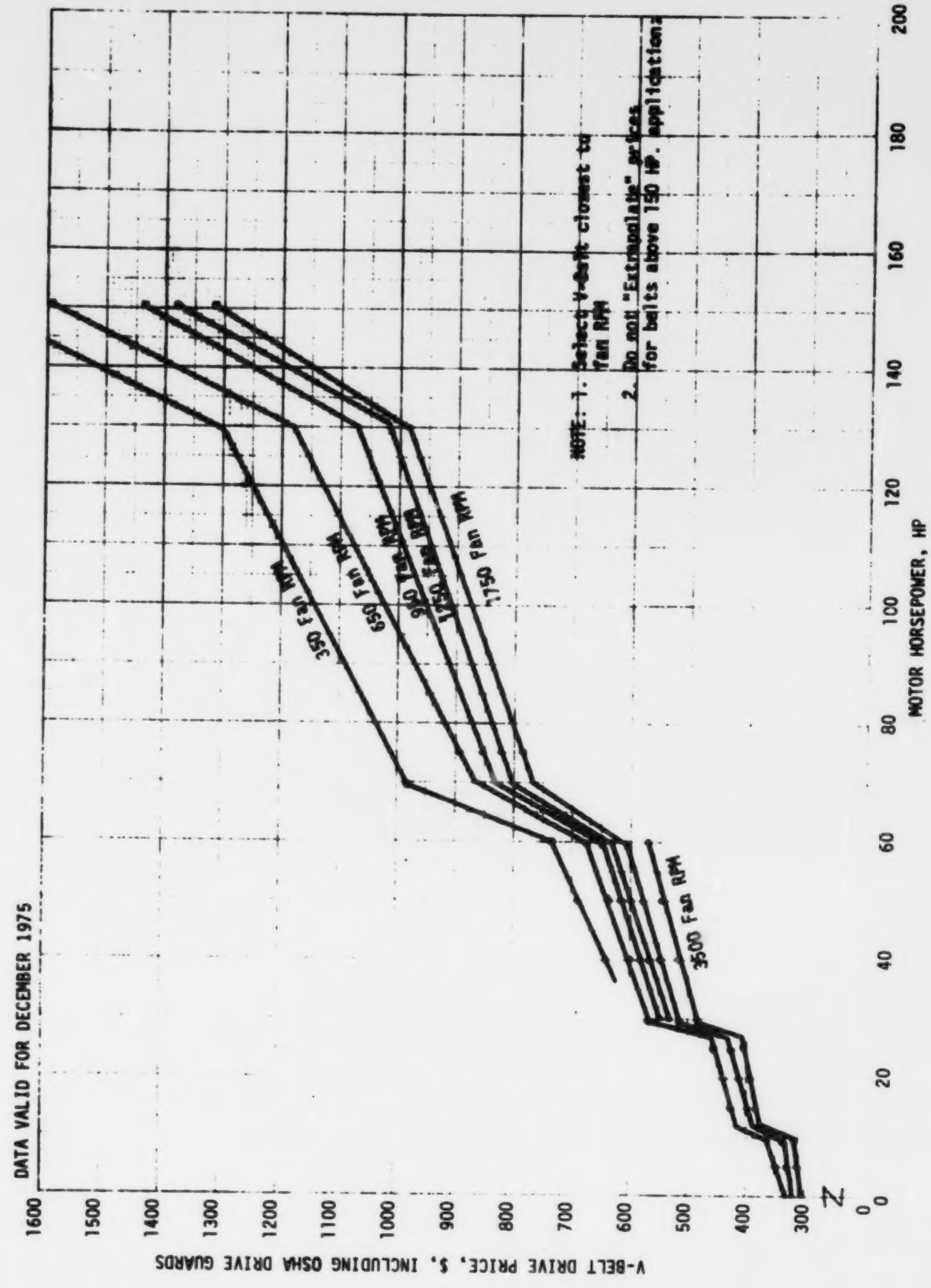
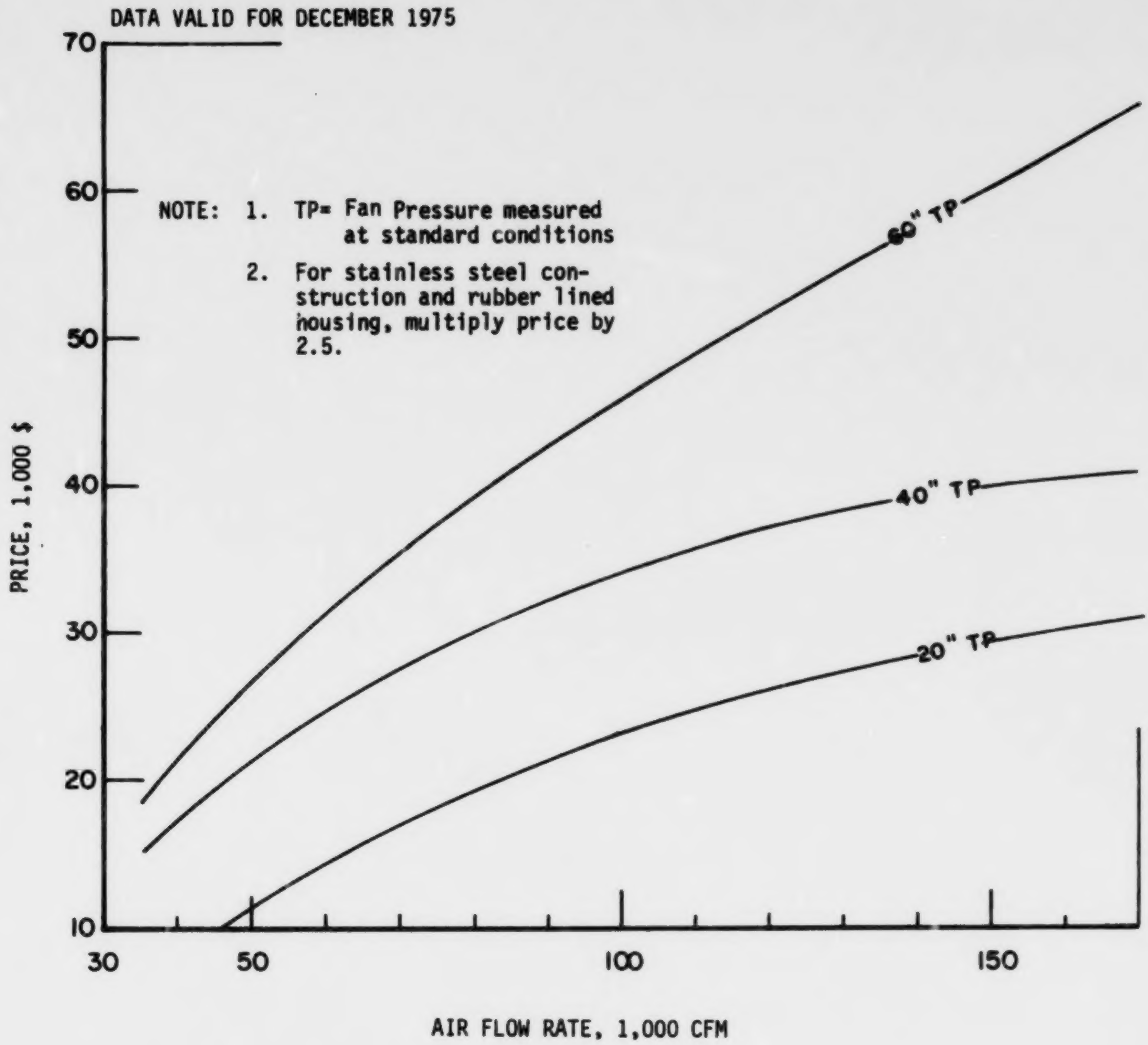


NOTE: 1. Select V-Belt closest to Fan RPM
2. Do not "Extrapolate" prices for belts above 150 HP. applications

Figure 4-45 V-BELT DRIVE PRICES



NOTE:

1. TP= Fan Pressure measured at standard conditions
2. For stainless steel construction and rubber lined housing, multiply price by 2.5.

Figure 4-46 RADIAL TIP FAN PRICES

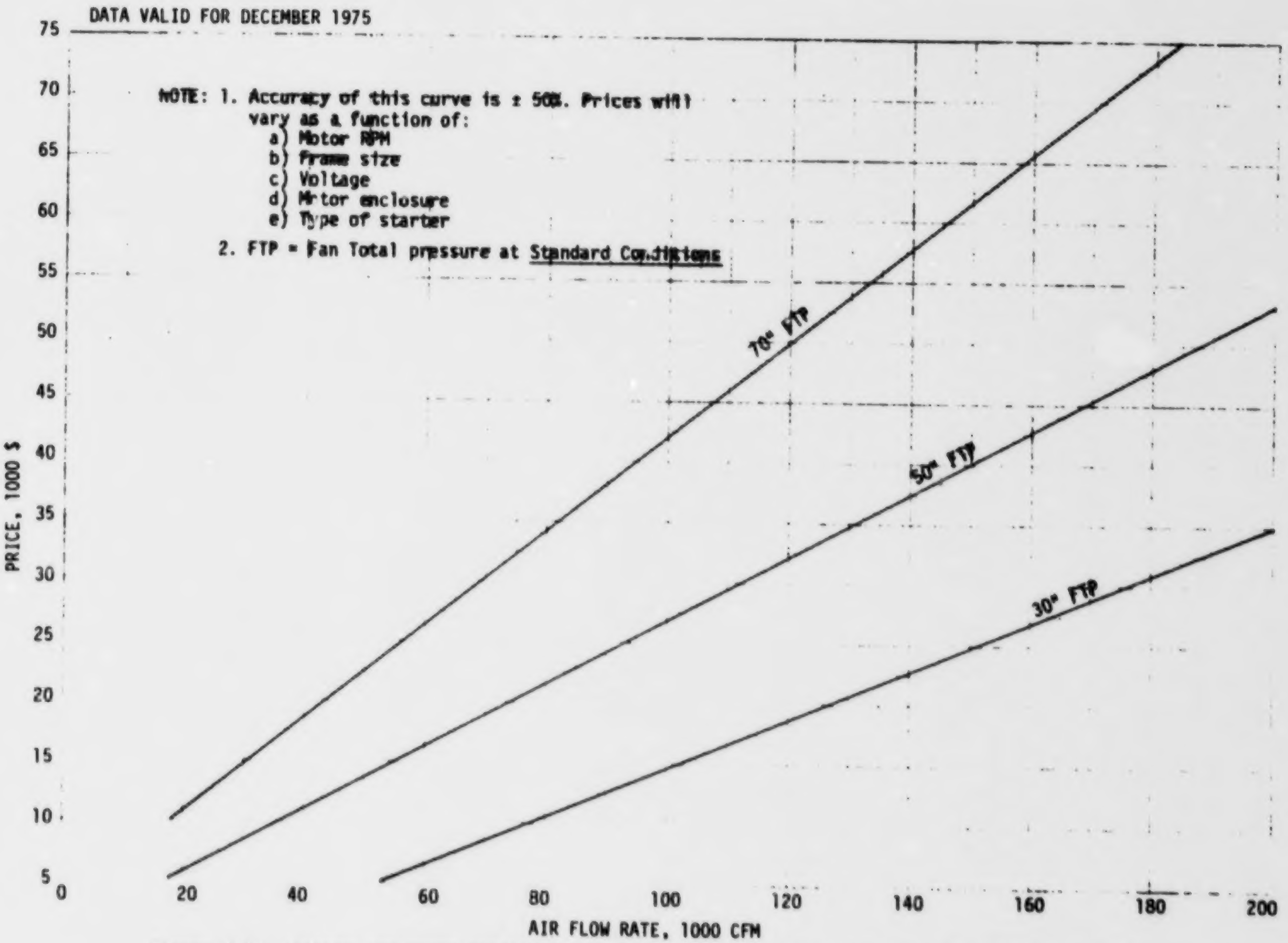


Figure 4-47 STARTER AND MOTOR PRICES FOR VENTURI SCRUBBER APPLICATIONS (HIGH PRESSURE, HIGH BHP)

4.11 STACKS

Prices for stacks are given in Figures 4-48, 4-49 and 4-50. Figures 4-48 and 4-49 are for carbon steel, unlined, uninstalled stacks under 100'. Figure 4-50 contains installed prices for tall stacks over 200' with and without liners and insulation.

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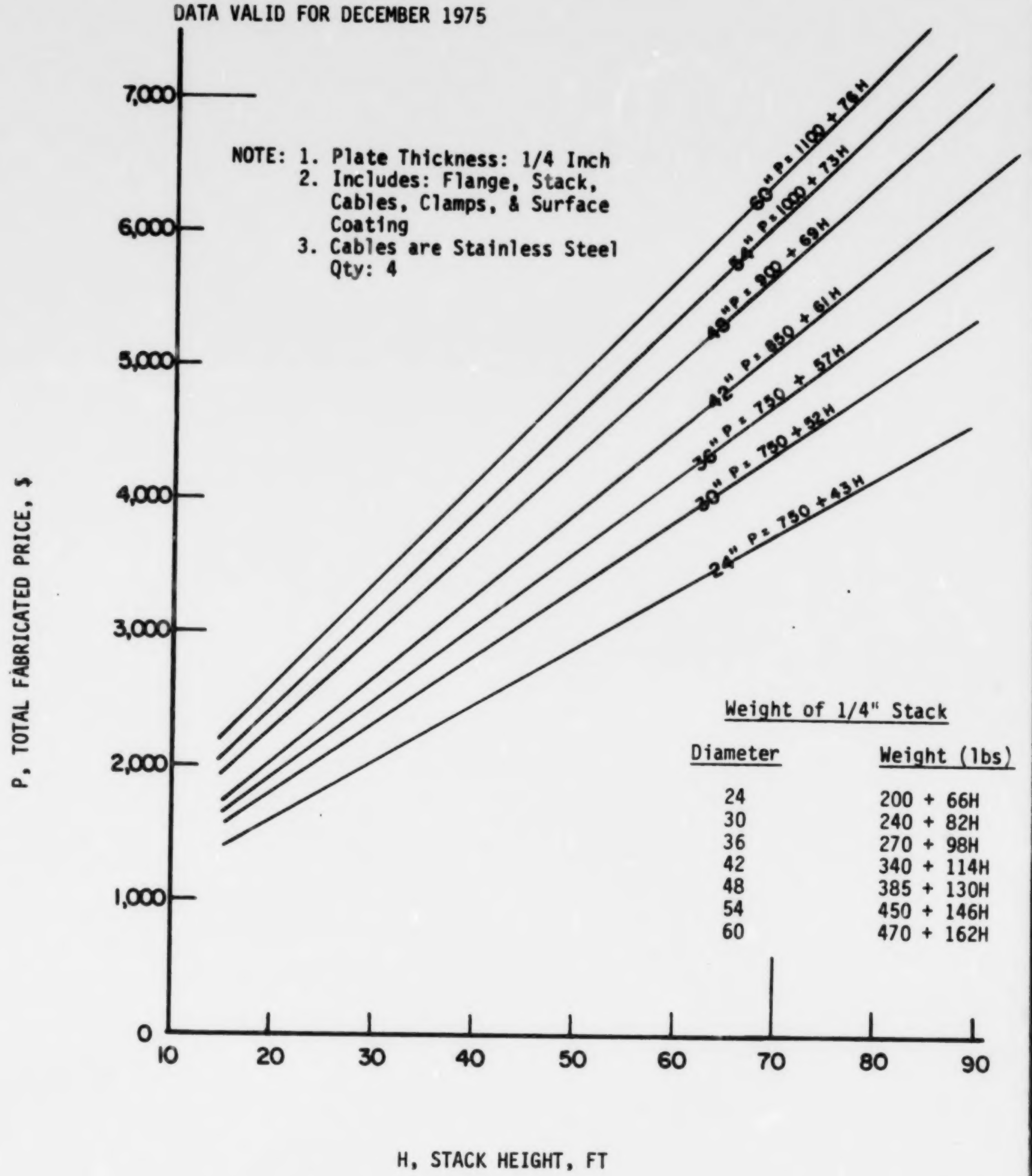

NOTE: 1. Plate Thickness: 1/4 Inch
2. Includes: Flange, Stack, Cables, Clamps, & Surface Coating
3. Cables are Stainless Steel Qty: 4

Weight of 1/4" Stack

Diameter	Weight (lbs)
24	200 + 66H
30	240 + 82H
36	270 + 98H
42	340 + 114H
48	385 + 130H
54	450 + 146H
60	470 + 162H

Figure 4-48 FABRICATED CARBON STEEL STACK PRICE VS. STACK HEIGHT AND DIAMETER FOR 1/4 INCH PLATE

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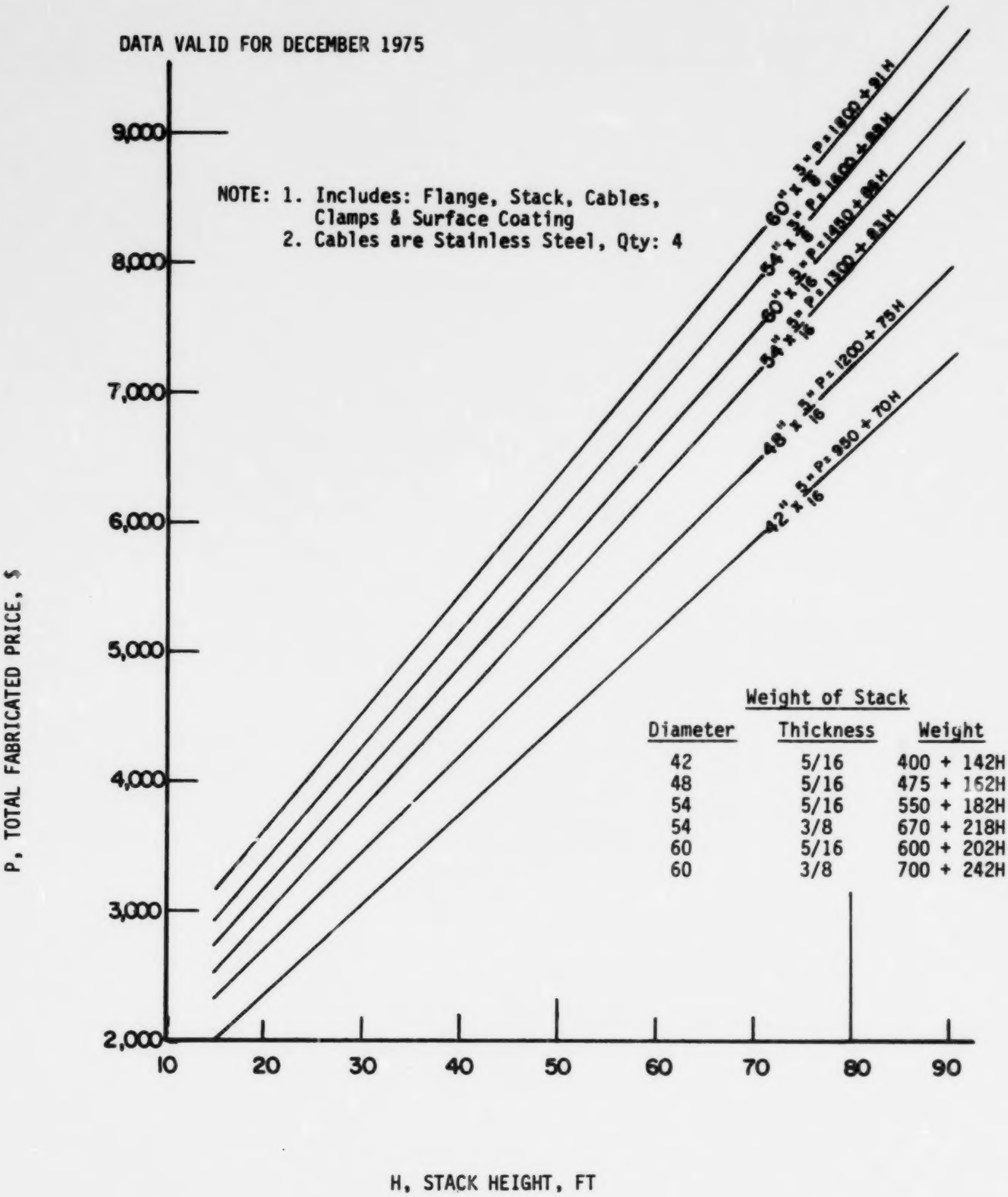

NOTE: 1. Includes: Flange, Stack, Cables, Clamps & Surface Coating
2. Cables are Stainless Steel, Qty: 4

Weight of Stack

Diameter	Thickness	Weight
42	5/16	400 + 142H
48	5/16	475 + 162H
54	5/16	550 + 182H
54	3/8	670 + 218H
60	5/16	600 + 202H
60	3/8	700 + 242H

Figure 4-49 FABRICATED CARBON STEEL STACK PRICE VS. STACK HEIGHT AND DIAMETER FOR 5/16 AND 3/8 INCH PLATE

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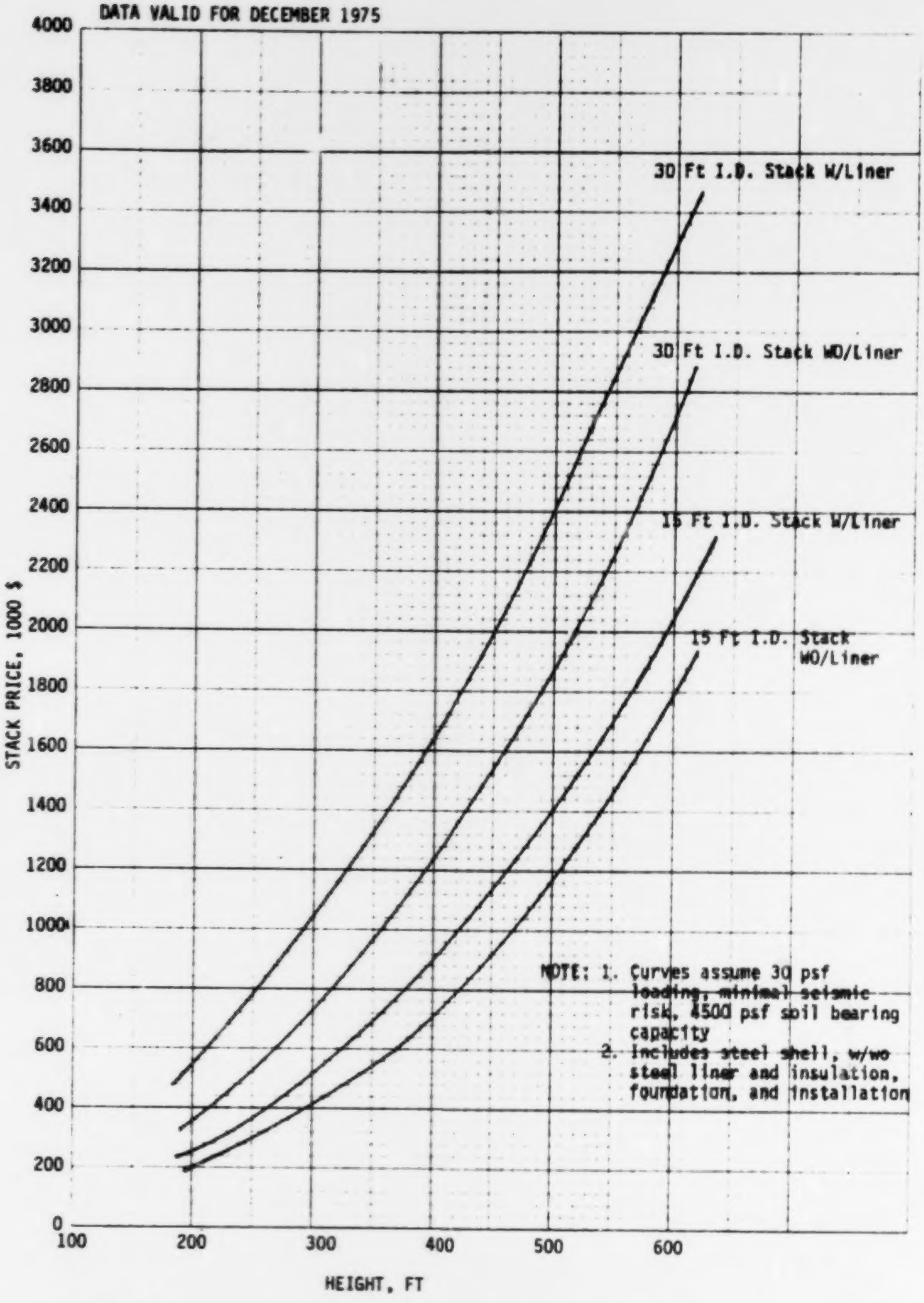


NOTE: 1. Curves assume 30 psf loading, minimal seismic risk, 4500 psf soil bearing capacity
2. Includes steel shell, w/wo steel liner and insulation, foundation, and installation

Figure 4-50 PRICES FOR TALL STEEL STACKS, INSULATED AND LINED

4.12 COOLING TOWERS

Two figures are given for pricing installed cooling towers. Figure 4-51 applies for capacities less than 1000 tons. Figure 4-52 applies for capacities over 1000 tons (1 ton = 12000 BTU/HR). The use of Figure 4-52 requires explanation.

Figure 4-52 provides prices for installed cooling towers as a function of the range and the water flow rate at a wet bulb (W.B.) temperature of 82F and an approach of 10F. See Table 4-11 for definitions of terminology. If the W.B. is other than 82F, Table 4-10 provides factors for adjusting the price. If the approach is other than 10F, Table 4-9 provides similar factors.

For example, suppose a cooling tower is to operate under conditions of 72F W.B. and a 20F approach (leaving water temperature = 92F). If the flow rate is 50,000 gpm and the range is 60F, then the price before adjustments is $540,000. The adjustment factor for 72F W.B. is 1.38 and the factor for a 20F approach is .5. The installed cooling tower price is thus:

$$(540{,}000 - 30{,}000)\ (0.5)\ (1.38) + 30{,}000 = \$381{,}900$$

The fan motor horsepower is estimated as follows:

$$HP = \frac{P}{1500}, \quad \text{where P is the price of the tower.}$$

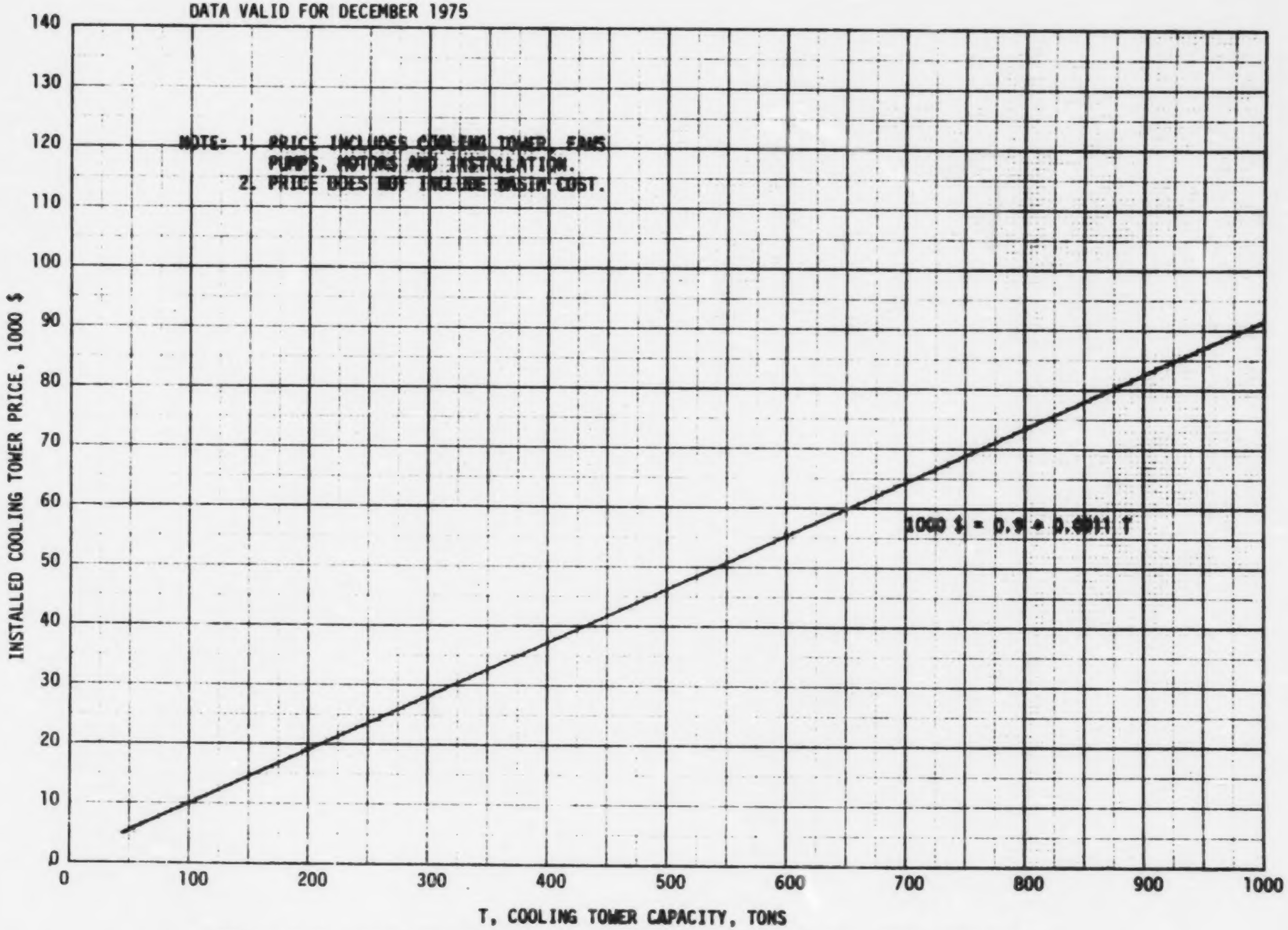
The pump motor horsepower is estimated as follows:

$$HP = gpm \times 0.12.$$

The basin area is estimated as follows:

$$\text{Basin Area} = \frac{P}{150}\ ft^2 .$$

Basin costs have not been provided since they are so highly dependant on the individual application. The basin may be used in conjunction with other processes, which involves a proration of costs, and the basin may be constructed in many types of soils and terrain, which can dramatically alter the first cost. Basin costs should be estimated on an application basis through a basin contractor.



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NOTE: 1. PRICE INCLUDES COOLING TOWER, FANS
PUMPS, MOTORS AND INSTALLATION.
2. PRICE DOES NOT INCLUDE BASIN COST.

Figure 4-51 PRICES FOR INSTALLED COOLING TOWERS FOR UNITS OF CAPACITY ≤ 1000 TONS

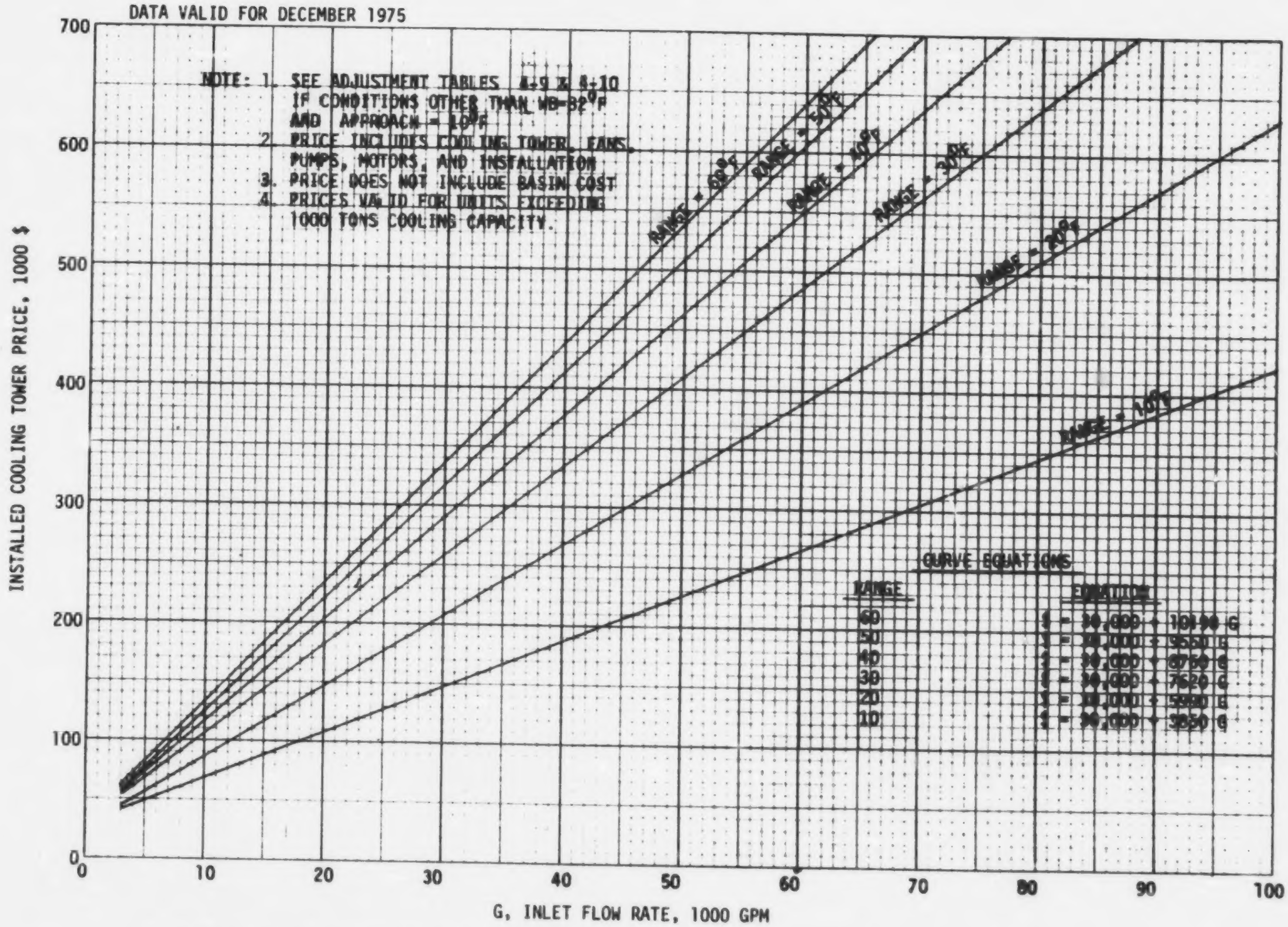


Figure 4-52 PRICES FOR INSTALLED COOLING TOWER BASED ON WET-BULB TEMPERATURE = 82°F AND APPROACH = 10°F

Table 4-9

PRICE ADJUSTMENT FACTORS *
FOR APPROACH ΔT

APPROACH, $\Delta ^{o}F$	FACTOR, F_1
6	1.60
8	1.20
10	1.00
12	.85
16	.65
20	.50
24	.40

Table 4-10

PRICE ADJUSTMENT FACTORS *
FOR WET BULB TEMPERATURES

WET BULB, ^{o}F	FACTOR, F_2
68	1.54
70	1.46
72	1.38
74	1.30
76	1.22
78	1.15
80	1.07
82	1.00

* NEW PRICE = $(P-30000)\ F_1F_2+30000$
WHERE P IS THE PRICE FROM Figure 4-52

Table 4-11

DEFINITIONS FOR COOLING TOWER

Approach: The difference between the average temperature of the circulating water leaving the device, and the average wet-bulb temperature of the entering air.
Range (cooling range): The difference between the average temperature of the water entering the device, and the average temperature of the water leaving it.
Temperature, dewpoint: the temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation (100 percent relative humidity) for a given absolute humidity at constant pressure.
Temperature, dry-bulb: the temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.
Temperature, wet-bulb: thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer constructed and used according to specifications.

4.13 PUMPS

Figures 4-53, 4-54 and 4-55 contain prices for 3550 RPM, 1750 RPM, and 1170 RPM cast iron, bronze fitted, vertical turbine wet sump pumps. These pumps can be used for scrubbers, cooling towers, water cooled duct, water supply, and the like. Prices are a function of pump head in feet and pump capacity in gpm. Figure 4-56 provides a means of estimating pump motor horsepower for a given pump head and capacity. Motor prices may then be estimated using Figure 4-41.

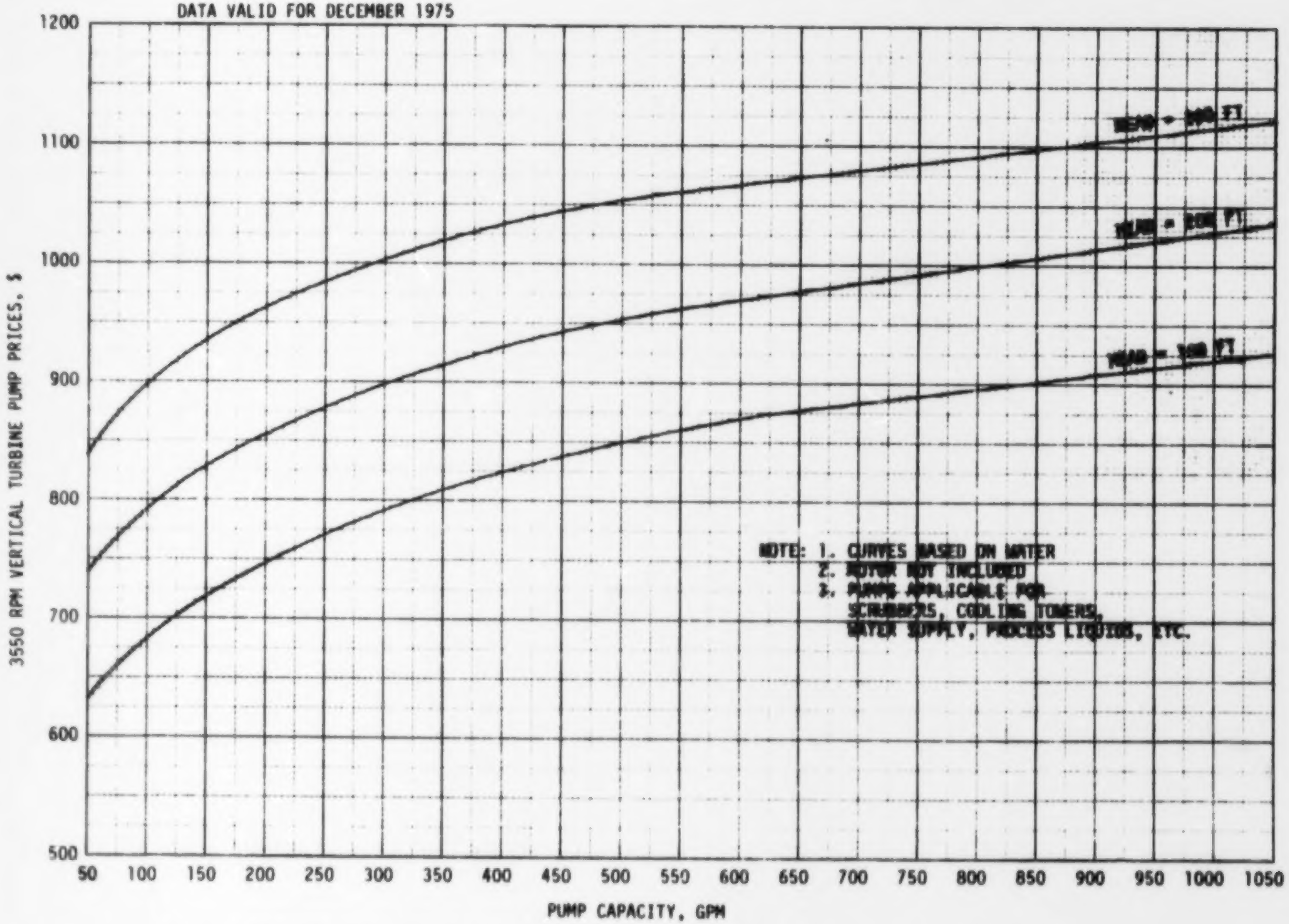


Figure 4-53 CAST IRON, BRONZE FITTED, VERTICAL TURBINE WET SUMP PUMP PRICES FOR 3550 RPM

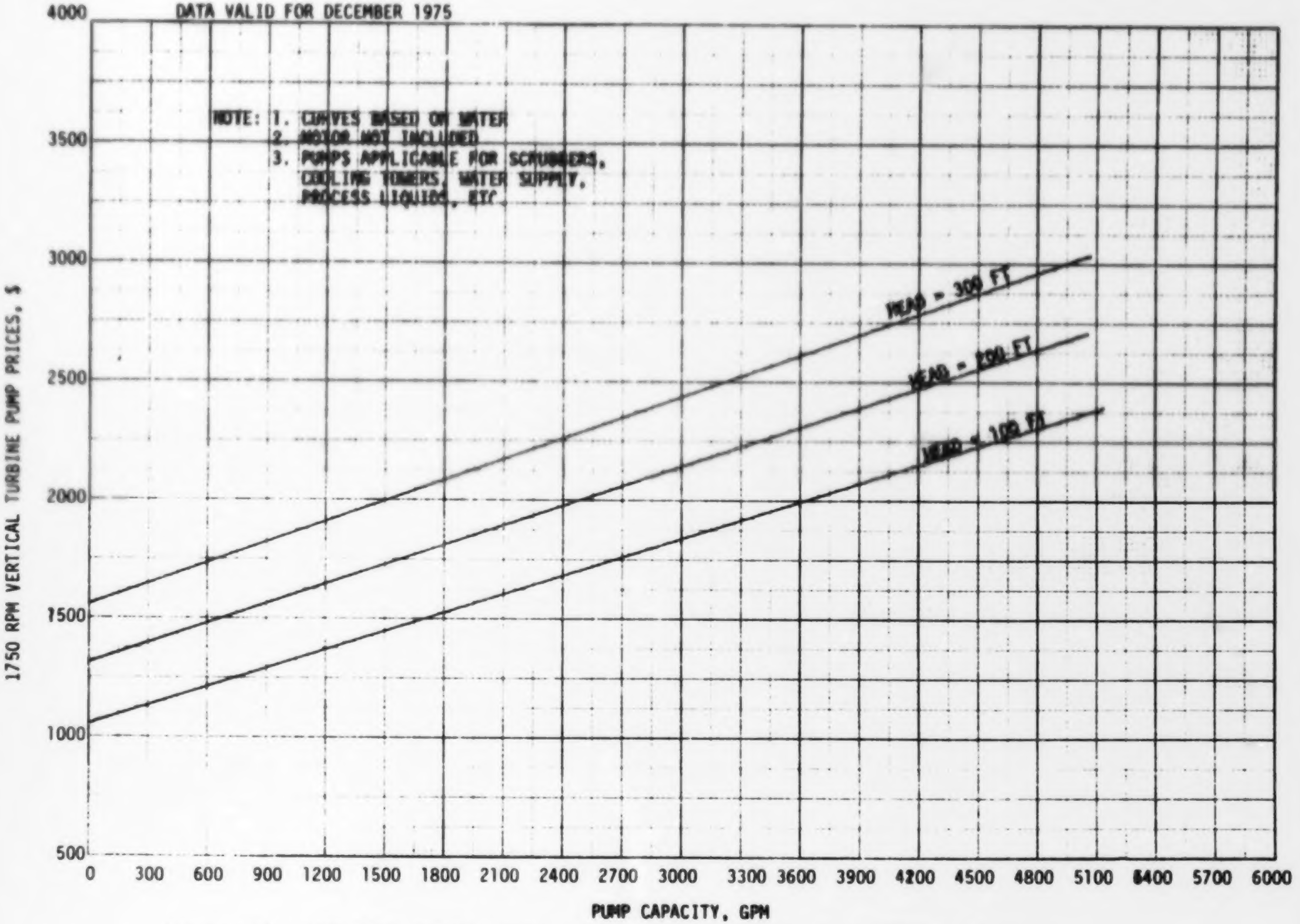
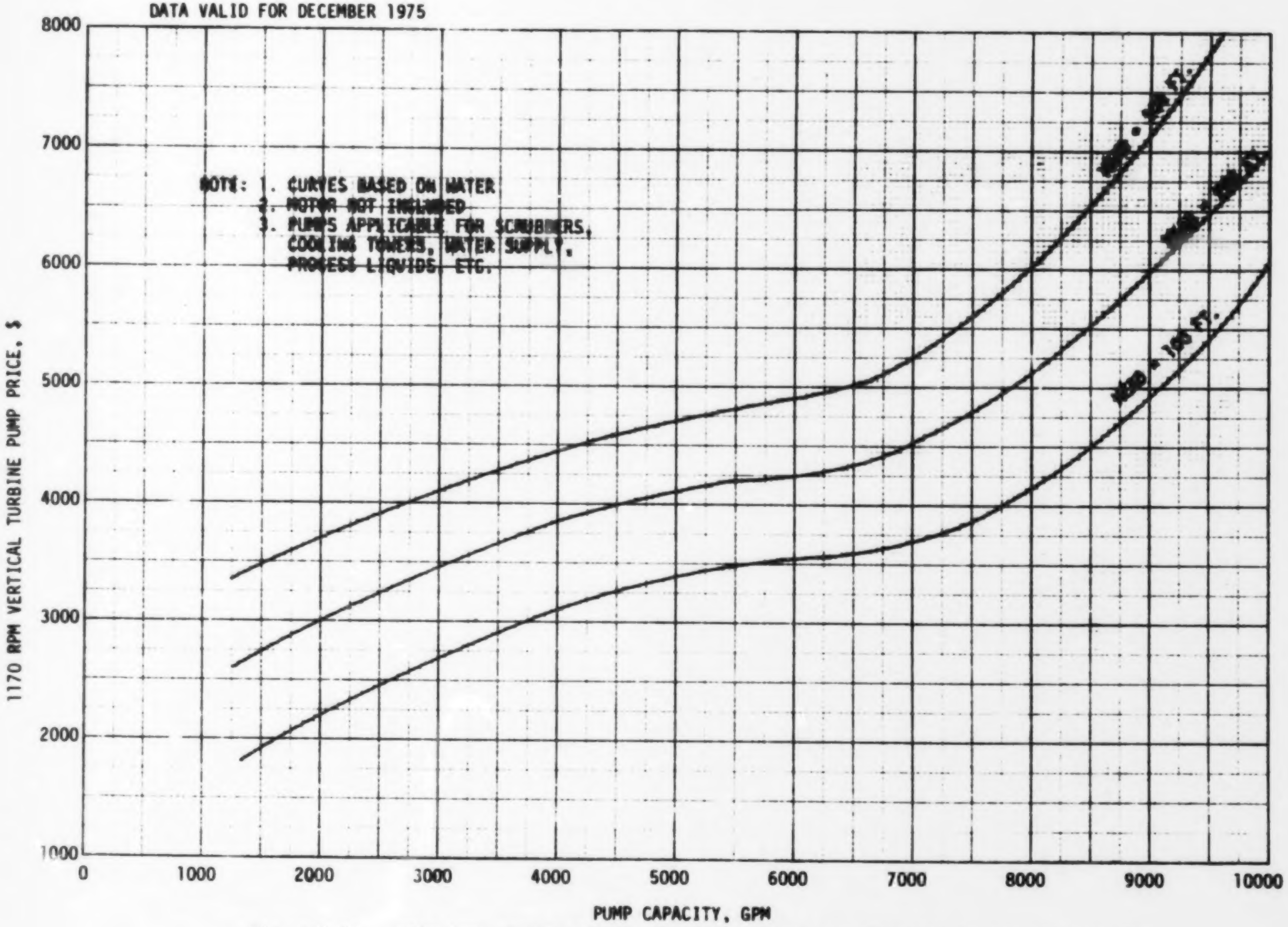


Figure 4-54 CAST IRON, BRONZE FITTED, VERTICAL TURBINE WET SUMP PUMP PRICES FOR 1750 RPM

DATA VALID FOR DECEMBER 1975



NOTE:
1. CURVES BASED ON WATER
2. MOTOR NOT INCLUDED
3. PUMPS APPLICABLE FOR SCRUBBERS, COOLING TOWERS, WATER SUPPLY, PROCESS LIQUIDS, ETC.

Figure 4-55 CAST IRON, BRONZE FITTED, VERTICAL TURBINE WET SUMP PUMP PRICES FOR 1170 RPM

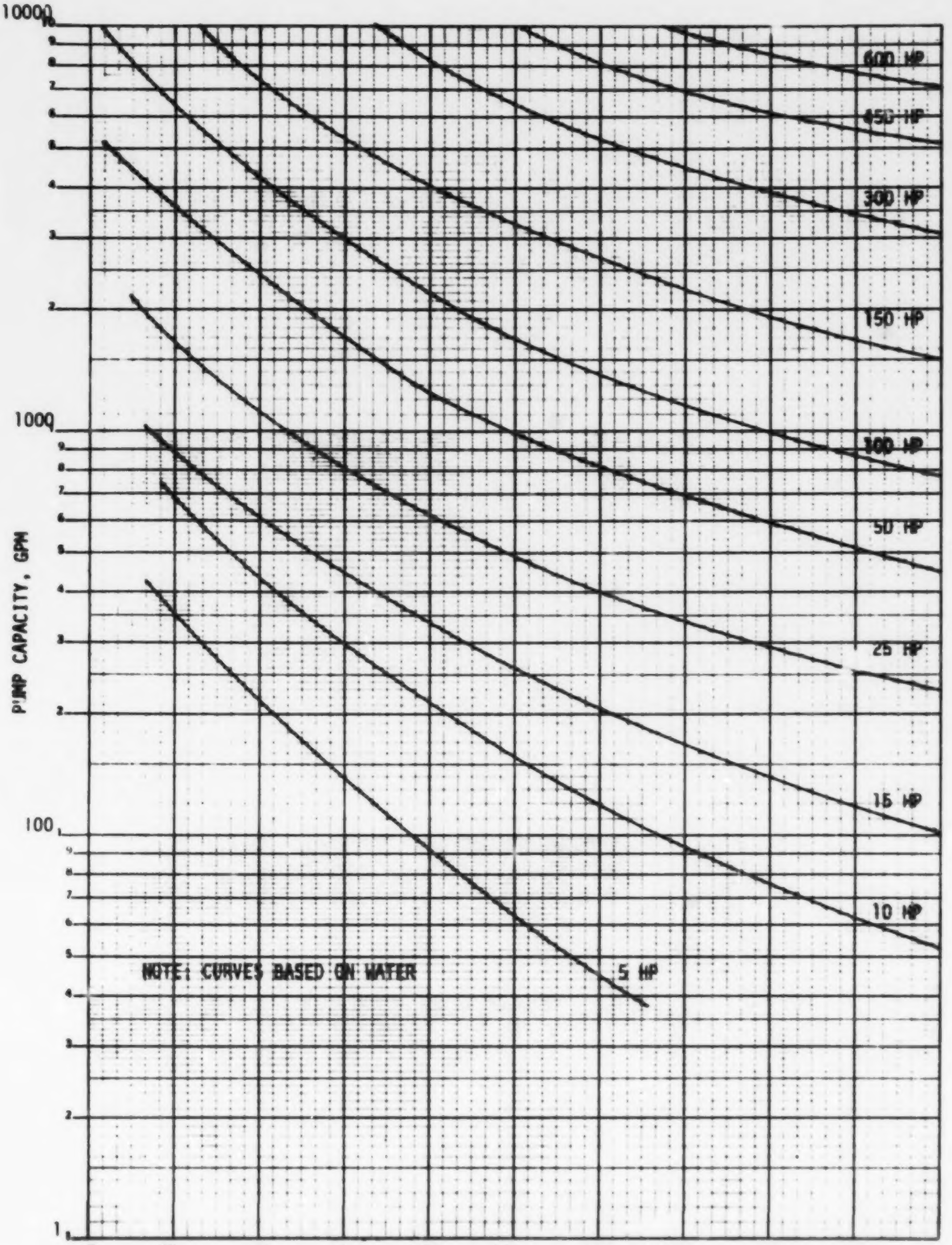


Figure 4-56 PUMP MOTOR HP VS. CAPACITY AND HEAD FOR VERTICAL TURBINE PUMPS

4.14 DUST REMOVAL EQUIPMENT

Figure 4-57 contains prices for screw conveyors as a function of conveyor length and diameter.

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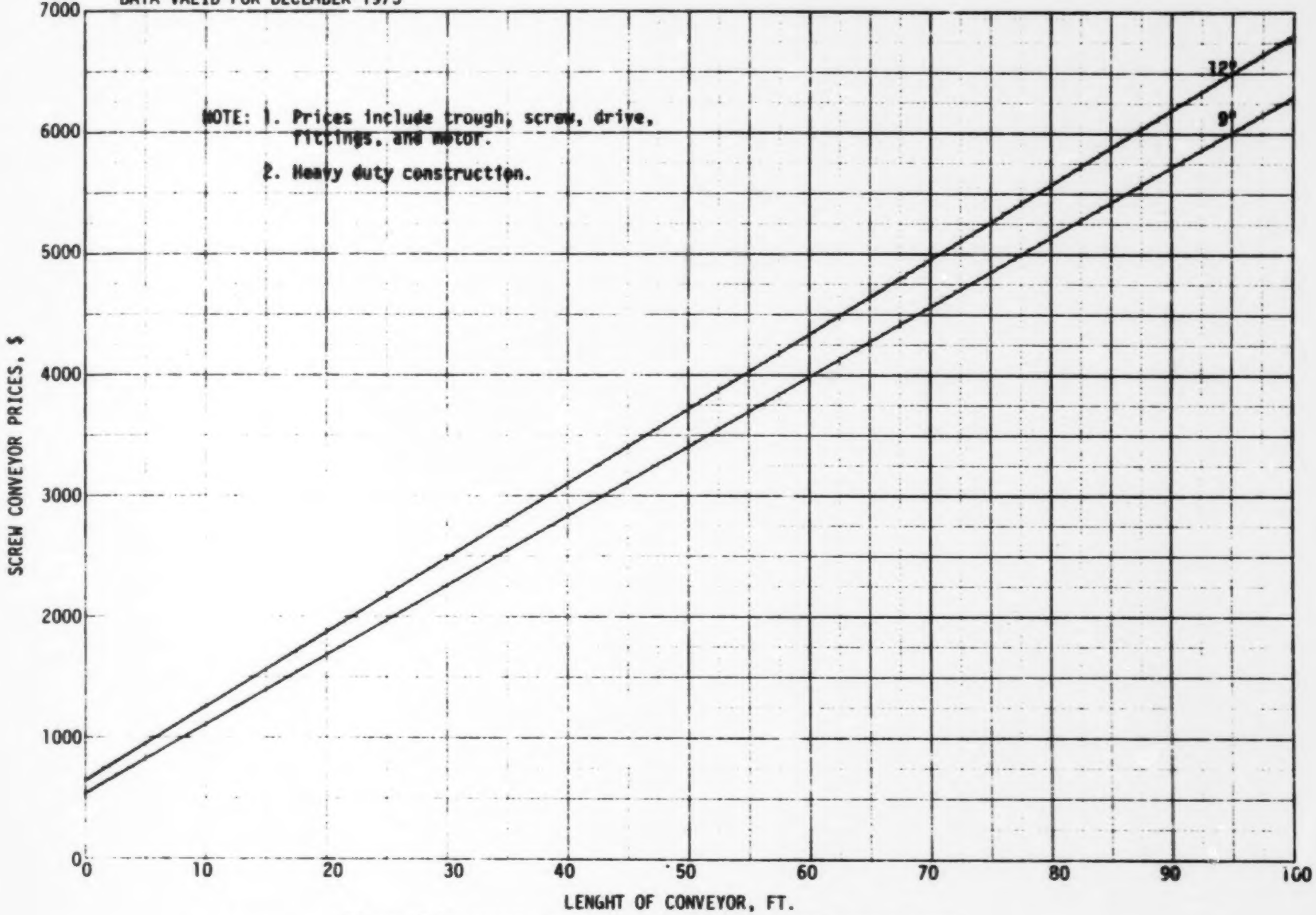

NOTE: 1. Prices include trough, screw, drive, fittings, and motor.

2. Heavy duty construction.

Figure 4-57 PRICES FOR SCREW CONVEYORS VS. LENGTH AND DIAMETER

4.15 OPERATION, MAINTENANCE, AND INSTALLATION COSTS

Figure 4-58 contains operating costs for electrostatic precipitator systems (from capture hood to stack exhaust) as a function of inlet gas volume to the precipitator and system power level in kilowatts per 1000 ACFM (1 HP = .746 KW). To estimate system power level, total the following:

- KW of fans
- KW of pumps
- KW of precipitator

Figure 4-59 gives operating costs for venturi scrubber systems (from capture hood to stack exhaust) as a function of inlet gas volume to the scrubber and actual static pressure at the fan.

Figure 4-60 provides operating costs for fabric filter systems (from capture hood to stack exhaust) as a function of inlet gas volume to the baghouse and actual static pressure at the fan. These prices do not include bag replacement, which must be estimated separately.

Table 4-12 gives installation costs for the five types of control systems, and maintenance costs for precipitators, scrubbers, and baghouses, expressed as a percent of purchased equipment cost. Equipment lives are also given.

Figure 4-61 contains operating and maintenance costs for thermal incinerators with and without heat exchangers versus hydrocarbon concentration and inlet gas volume. The gas volume is measured before entering the heat exchanger for those units employing them. Figure 4-62 contains operating and maintenance costs for catalytic incinerators with and without heat exchangers versus inlet gas volume and hydrocarbon concentration.

Figure 4-63 gives operating and maintenance costs for carbon adsorbers versus inlet gas volume and hydrocarbon concentration.

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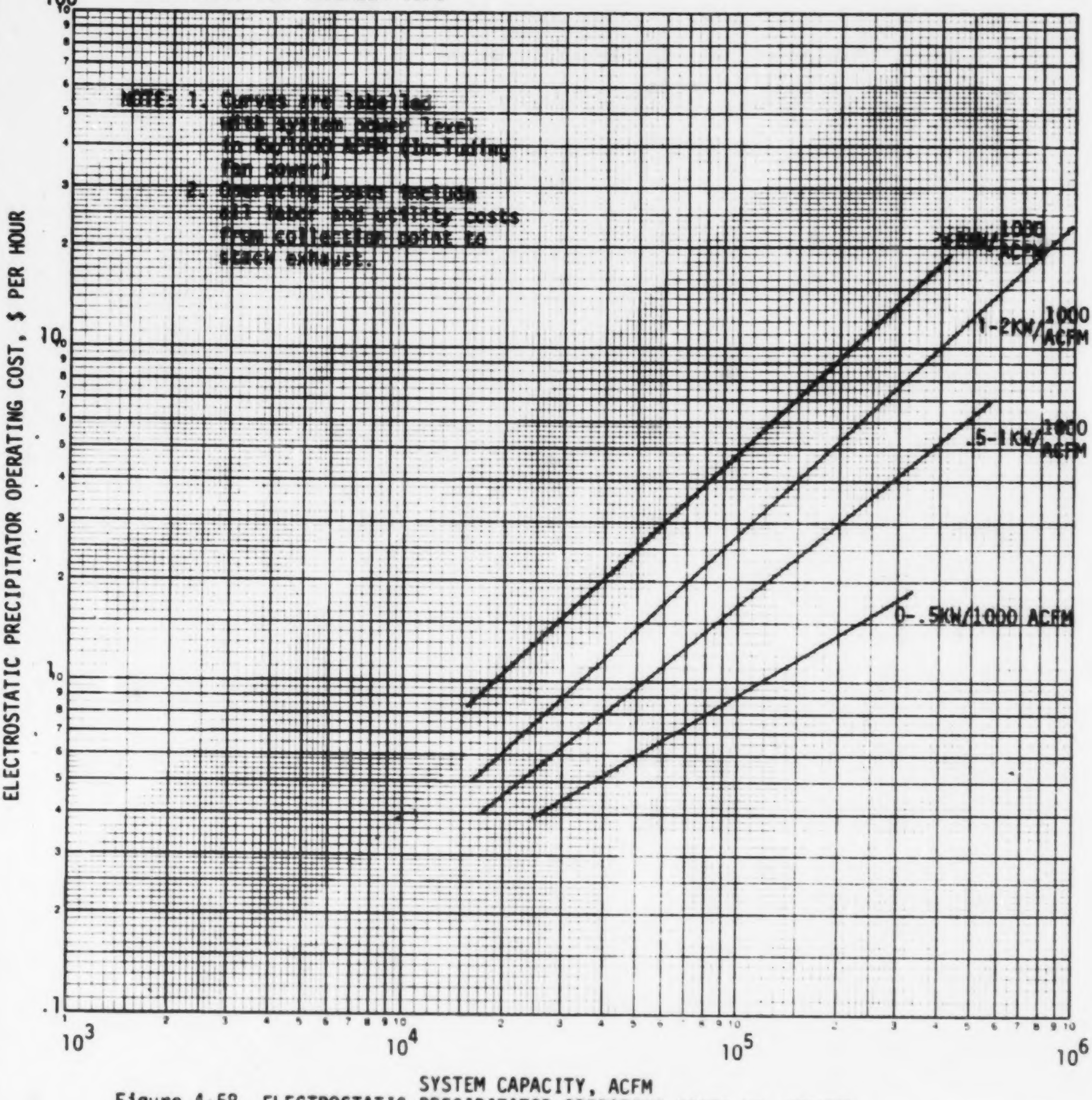

Figure 4-58 ELECTROSTATIC PRECIPITATOR OPERATING COSTS VS. VOLUME AND POWER CONSUMPTION

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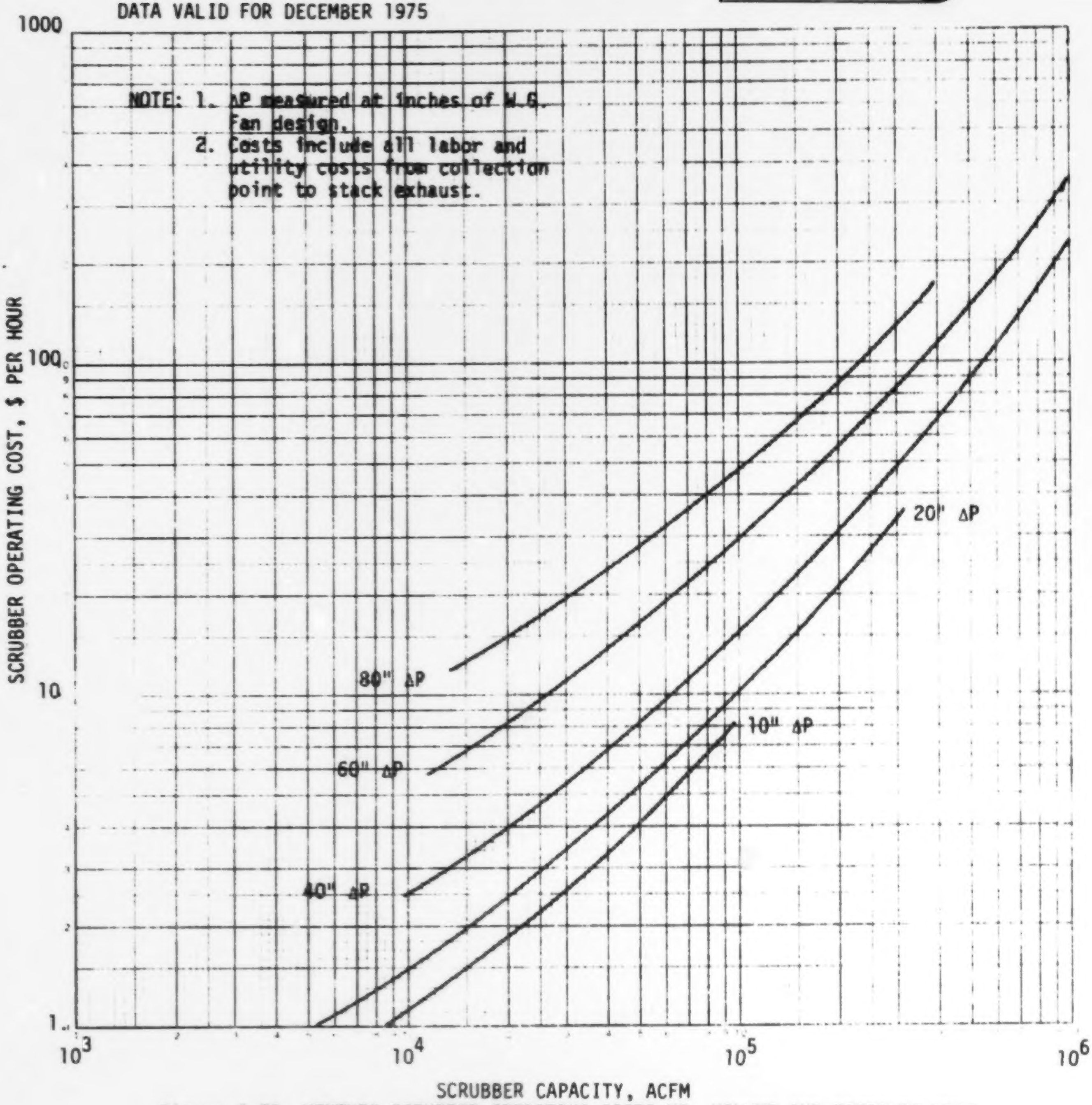
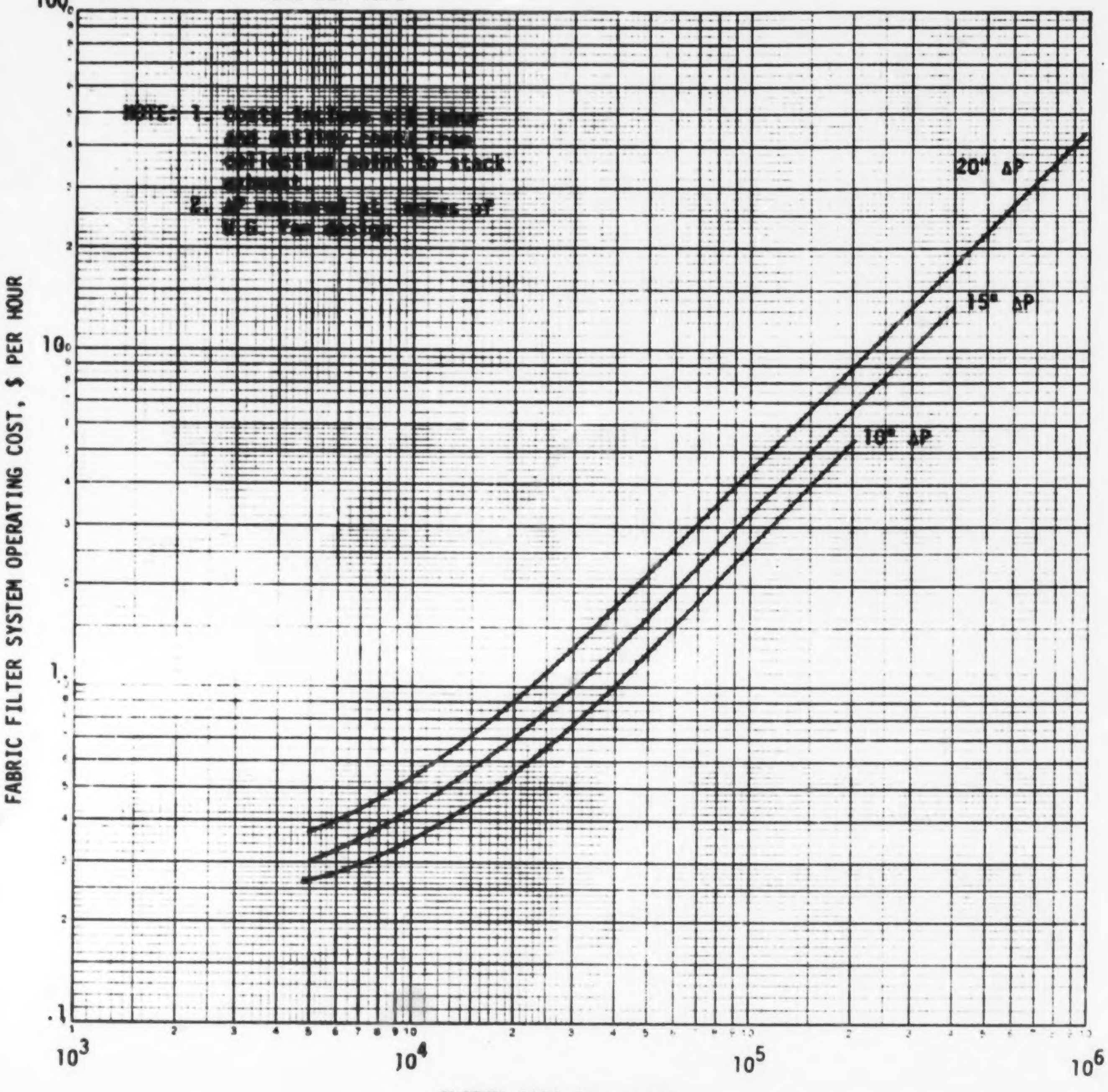

DATA VALID FOR DECEMBER 1975

NOTE: 1. ΔP measured at inches of W.G. Fan design.
2. Costs include all labor and utility costs from collection point to stack exhaust.

Figure 4-59 VENTURI SCRUBBER OPERATING COSTS VS. VOLUME AND PRESSURE DROP

DATA VALID FOR DECEMBER 1975



NOTE: 1. Costs include [illegible] labor and utility costs from collection point to stack exhaust.
2. ΔP [illegible] at inches of W.G. Fan design.

Figure 4-60 FABRIC FILTER OPERATING COSTS VS. VOLUME AND PRESSURE DROP

Table 4-12. MAINTENANCE AND INSTALLATION COST FACTORS, AND EQUIPMENT LIFE GUIDELINES

NOTE: Estimate maintenance and installation costs as percent of total equipment purchase price. Also note that a low installation percentage does not imply low maintenance or a short equipment life. These guidelines are estimates of the range of values that have been experienced in the industry. The choice of one over another depends on the application.

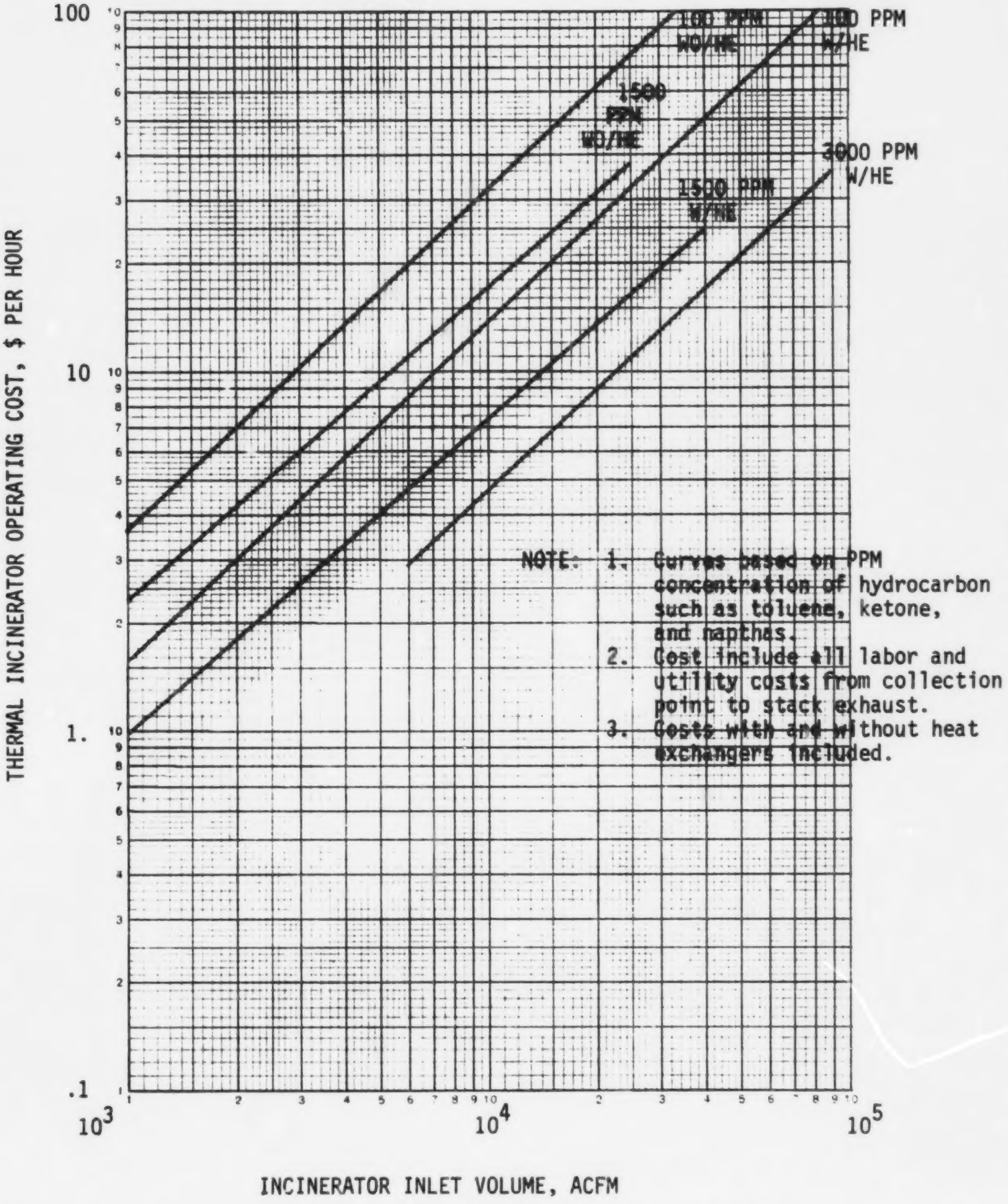
Table 4-12a	Low	Average	High	Very high
Maintenance				
Electrostatic precipitators	1%	2%	4%	10%
Venturi scrubbers	8%	13%	18%	40%
Fabric filters	1%	2%	5%	7%

Table 4-12b	Low	Average	High	Very high
Bag life	4 mos.	1.5 yrs.	5 yrs.	10 yrs.

Table 4-12c	Low	Average	High	Very high
Installation				
Electrostatic precipitators	50%	75%	120%	200%
Venturi scrubbers	70%	140%	220%	350%
Fabric filters	40%	75%	120%	170%
Incinerators (wo/HE)	30%	50%	70%	90%
Incinerators (w/HE)	25%	45%	65%	90%
Adsorbers	30%	50%	70%	90%

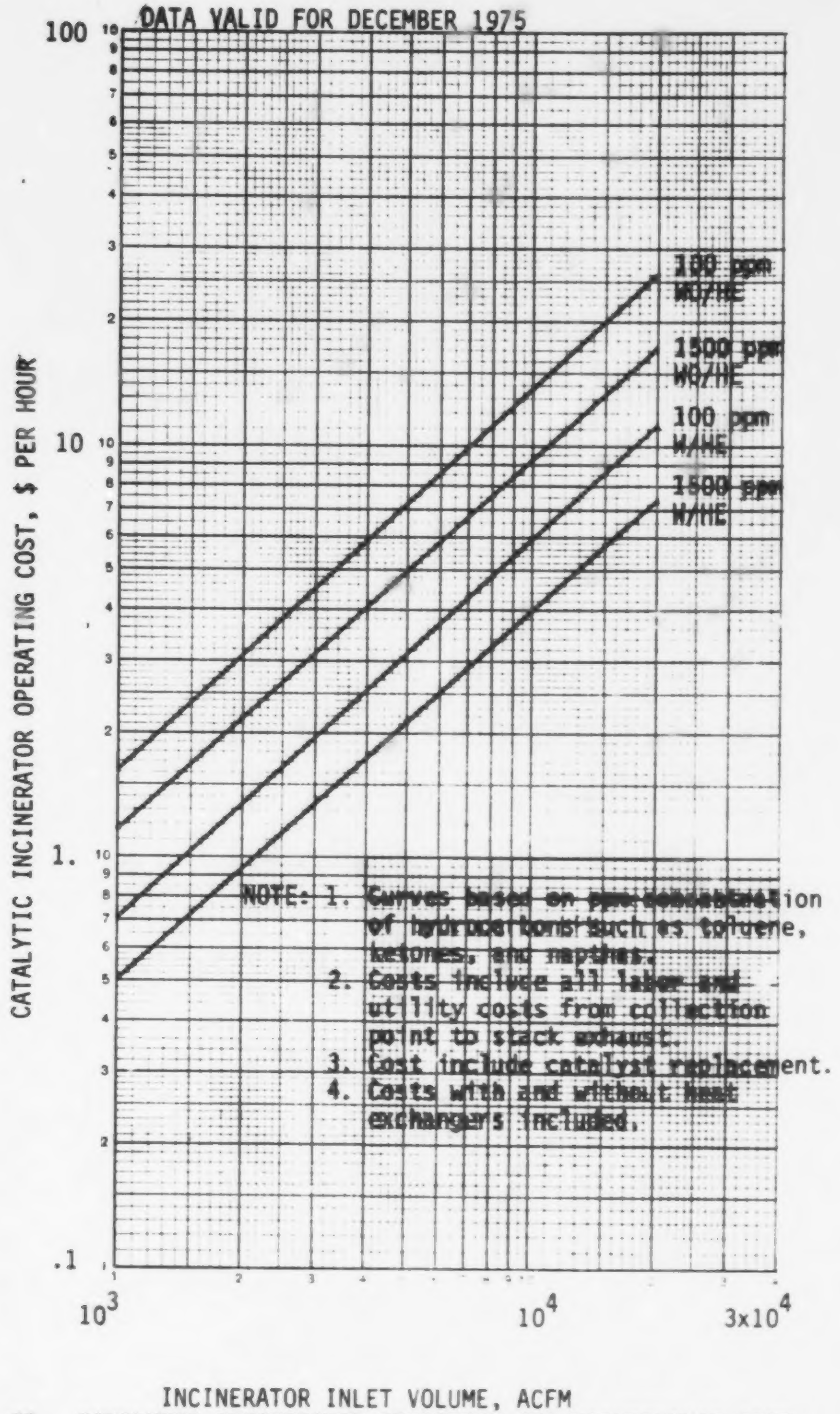
Table 4-12d	Short	Average	Long
Equipment Life			
Electrostatic precipitators	5 yr.	20 yr.	40 yr.
Venturi scrubbers	5 yr.	10 yr.	20 yr.
Fabric filters	5 yr.	20 yr.	40 yr.
Thermal incinerators	5 yr.	10 yr.	20 yr.
Catalytic incinerators	5 yr.	10 yr.	20 yr.
Adsorbers	5 yr.	10 yr.	20 yr.

DATA VALID FOR DECEMBER 1975



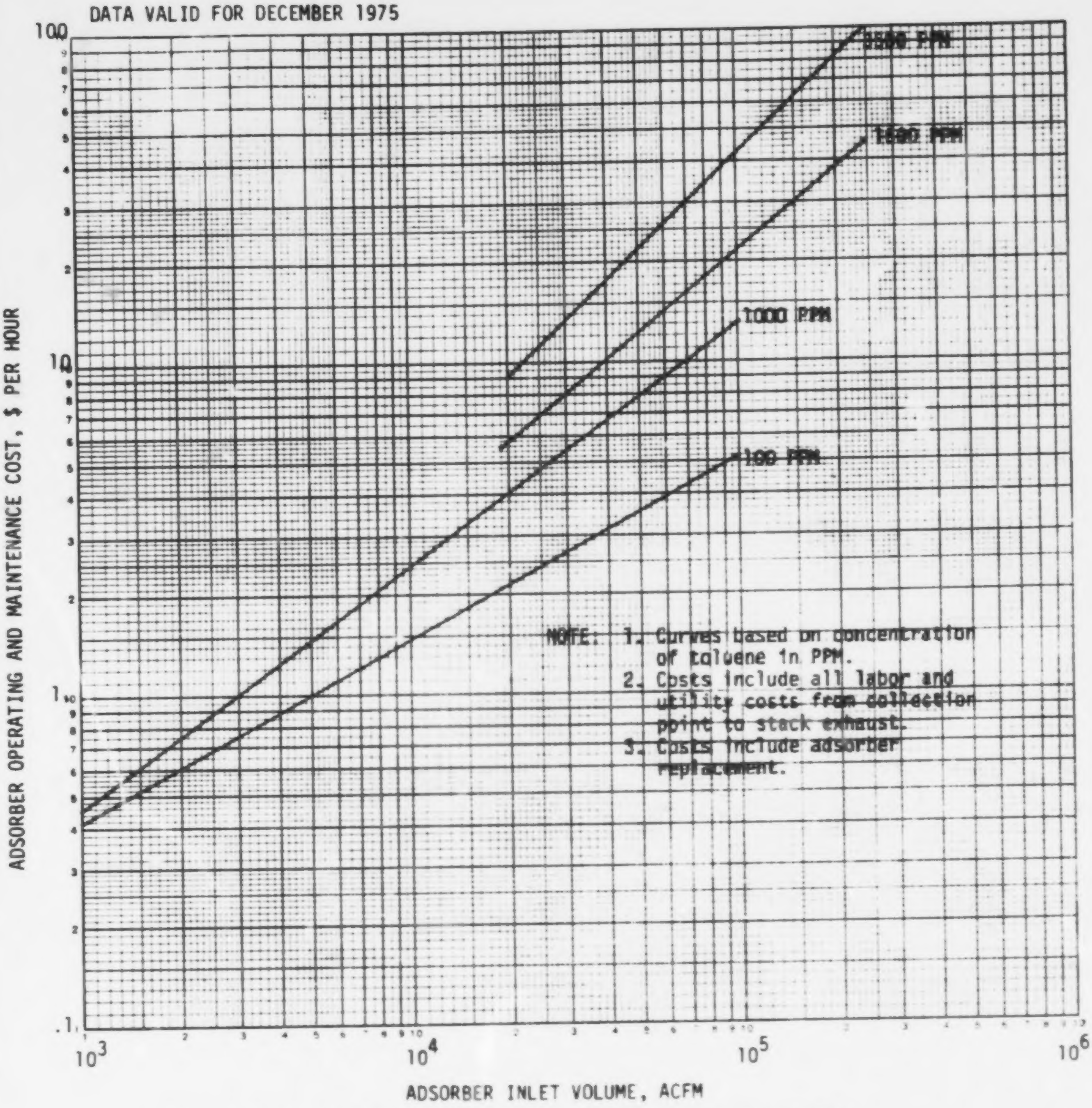
NOTE:
1. Curves based on PPM concentration of hydrocarbon such as toluene, ketone, and napthas.
2. Cost include all labor and utility costs from collection point to stack exhaust.
3. Costs with and without heat exchangers included.

Figure 4-61 THERMAL INCINERATOR OPERATING AND MAINTENANCE COST VS. VOLUME AND HYDROCARBON CONCENTRATION



NOTE:
1. Curves based on ppm concentration of hydrocarbons such as toluene, ketones, and napthas.
2. Costs include all labor and utility costs from collection point to stack exhaust.
3. Cost include catalyst replacement.
4. Costs with and without heat exchangers included.

Figure 4-62 CATALYTIC INCINERATOR OPERATING AND MAINTENANCE COST VS. VOLUME AND HYDROCARBON CONCENTRATION



NOTE:
1. Curves based on concentration of toluene in PPM.
2. Costs include all labor and utility costs from collection point to stack exhaust.
3. Costs include adsorber replacement.

Figure 4-63 CARBON ADSORPTION UNIT OPERATING AND MAINTENANCE COST VS. VOLUME AND HYDROCARBON CONCENTRATION

SECTION 5

UPDATING COSTS TO FUTURE TIME PERIODS

5.1 GENERAL

The methods for updating the costs given in this manual are contained in this section. A separate procedure is described for each equipment type or cost item-these procedures have been used to adjust old cost data to December 1975 levels, when necessary, and these procedures are recommended for updating the costs for future time periods. They have been kept as simple as possible. No attempt is made to predict future costs, since this is beyond the scope of this manual. In general, the methods involve use of the Chemical Engineering (CE) plant cost indexes and U.S. Department of Labor, Bureau of Labor Statistics (BLS) wholesale price indexes. Selected index accounts are contained in Appendix B.

These two sets of indexes were selected for applicability, consistency, specificity, and availability. The CE index includes such process industries as (among others):

a. chemicals and petrochemicals
b. fertilizers and agricultural chemicals
c. lime and cement
d. man-made fibers
e. paints, varnishes, pigments, and allied products
f. petroleum refining
g. soap glycerin and related products
h. wood, pulp, paper, and board
i. plastics

These industries are representative of the industries under the attention of this manual. The CE indexes are based on 1957-1959 = 100 and are adjusted for labor productivity changes-not found in other cost indexes. There is complete back-up information available regarding the make-up of the indexes, hence it is possible to modify the indexes to suit particular needs (see Arnold, T. H. and Chilton, C. H., New Index Shows Plant Cost Trends, Chemical Engineering, Feb. 18, 1963, pp. 143-149. Also refer to Appendix C, Source Nos. 130 & 131).

Table B-1 gives the CE indexes as far back as 1957. Figure 5-1 shows how the overall CE plant index has changed since its inception. The following are descriptions of the indexes regularly published by Chemical Engineering.

A. ENGINEERING & SUPERVISION

Engineering and Supervision is 10% of the total plant index. It includes the following:

- 33% Engineers
- 47% Draftsmen
- 20% Clerical

B. BUILDINGS

Buildings is 7% of the total plant index and is based on a special BLS construction index in which the ratio of materials to labor is 53:47.

C. ERECTION & INSTALLATION LABOR

Erection and Installation Labor is 22% of the total plant index. This is the average hourly earning as determined by the BLS for the contract construction industry.

D. EQUIPMENT, MACHINERY, SUPPORTS

Equipment, Machinery and Supports consists of 61% of the total plant index. This index consists of:

1. Fabricated Equipment-37%

   Such as:
   - a. boilers, furnaces, and heaters
   - b. columns and towers
   - c. heat exchangers
   - d. condensers and reboilers
   - e. process drums
   - f. reactors
   - g. pressure vessels and tanks
   - h. storage tanks and spheres
   - i. evaporators

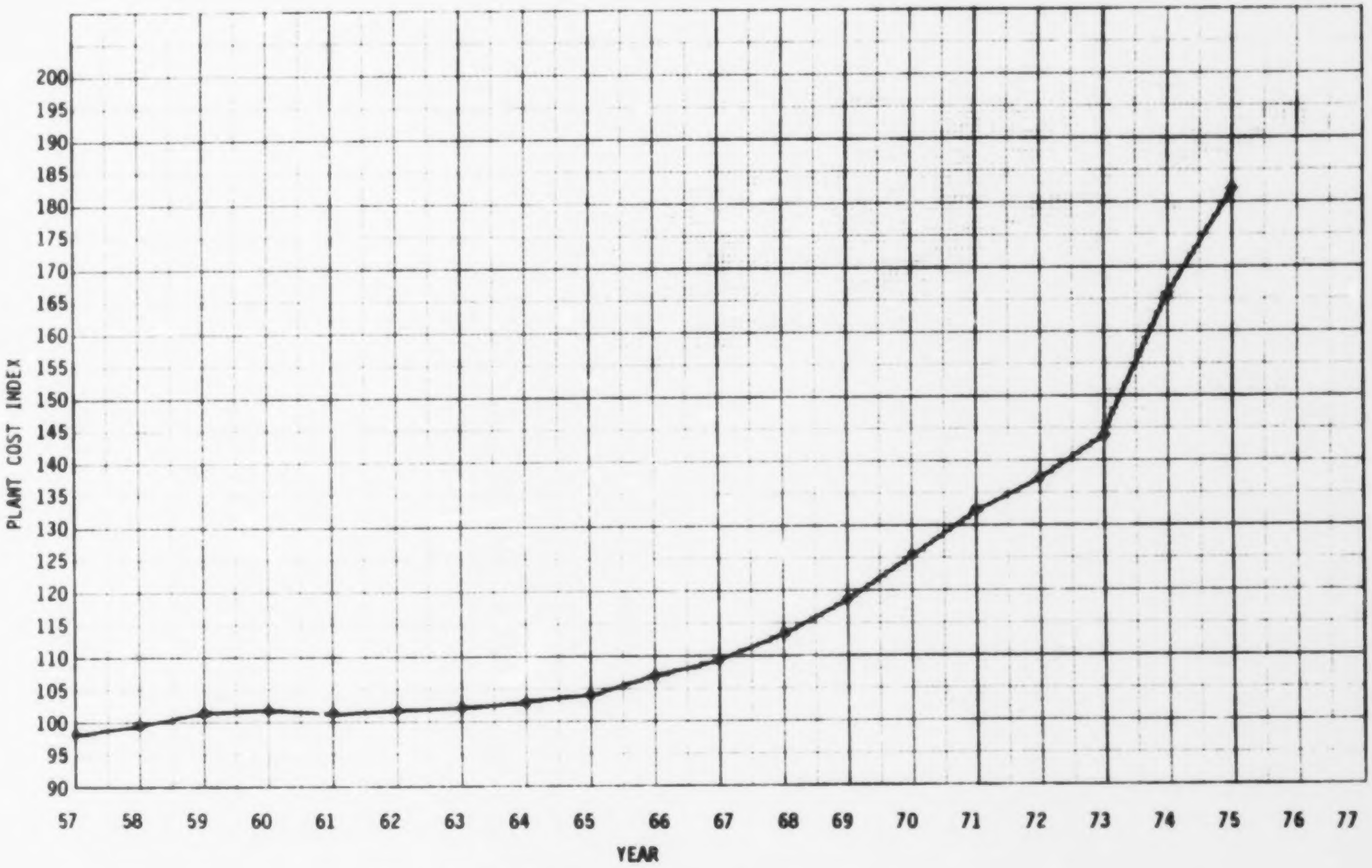


Figure 5-1 CHEMICAL ENGINEERING PLANT COST INDEX

2. Process Machinery-14%
   "Off the shelf" items such as:
   - a. centrifuges
   - b. filters
   - c. mixing and agitating equipment
   - d. rotary kilns and dryers
   - e. conveyors and bucket elevators
   - f. high-pressure vacuum or refrigeration producing equipment
   - g. extruders
   - h. crushing and grinding equipment
   - i. thickeners and settlers
   - j. fans and blowers

3. Pipe, Valves, and Fittings-20%

4. Process Instruments and Controls-7%

5. Pumps and Compressors-7%

6. Electrical Equipment and Materials-5%
   Such as:
   - a. electric motors
   - b. transformers
   - c. switch gear
   - d. wire and cable

7. Structurals, Supports, Insulation, and Paint-10%
   Such as:
   - a. structural steel
   - b. foundation materials
   - c. insulation
   - d. lumber
   - e. paint

Cost elements not included in the CE indexes include:

- a. site clearing and preparation
- b. insurance and taxes during construction
- c. company overhead allocated to the project
- d. contractor's overhead

For purposes of this manual, the CE indexes have been used whenever there is no specifically applicable BLS wholesale price index. The BLS indexes used are given in Tables B-2 thru B-20; the specific commodities and associated BLS code number and year of reference are listed below:

Code No.	Base Year=100	Commodity	Table No.
0312	1967	Cotton Broadwoven Goods	B-2
0334	1967	Manmade Fiber Broadwoven Goods	B-3
05310101	1967	Natural Gas	B-21
0543	Dec/1970	Industrial Power	B-22

Code No.	Base Year=100	Commodity	Table No.
07	1967	Rubber and Plastic Products	B-4
10130246	1967	A-36, Carbon Steel Plates	B-5
10130247	1967	Stainless Steel Plate	B-6
10130262	1967	Carbon Steel Sheet	B-7
10130264	1967	Stainless Steel Sheet	B-8
1141	1967	Pumps, Compressors, and Equipment	B-9
11450133	1967	V-Belt Sheaves	B-10
1147	1967	Fans and Blowers, Except Portable	B-11
11730112	1967	10 HP, AC Motors	B-12
11730113	1967	250 HP, AC Motors	B-13
11730119	1967	50 HP, AC Motors	B-14
11750781	1967	75 HP, 440 volt, AC Starters	B-15
135	1967	Refractories	B-16
13520111	1967	Fire Clay Brick, Super Duty	B-17
13520131	1967	High Alumina Brick, 70 Pct.	B-18
13520151	Dec/1974	Castable Refractories	B-19
1392	1967	Insulation Materials	B-20

5.2 EQUIPMENT COST UPDATING PROCEDURES

Using these indexes, the procedures for updating the purchase costs of each equipment type will now be discussed.

Electrostatic Precipitators

Use CE Fabricated Equipment index. For precipitators with insulation, use the following composite index on the additional cost only:
½ (BLS #1392 factor) + ½ (CE Fabricated Equipment factor).

Venturi Scrubbers

Use CE Fabricated Equipment index. For rubber liners use BLS #07 on the liner cost only.

Fabric Filters

Use CE Fabricated Equipment index. For filters with insulation, use same procedure as for precipitators with insulation. For stainless steel construction, use BLS #10130264 on the additional cost. For filter media use BLS #0312 or #0334.

Thermal and Catalytic Incinerators

Use CE Fabricated Equipment index for custom units. Use CE Process Equipment index for package units.

Adsorbers

Same as for thermal and catalytic incinerators.

Ductwork

Use CE Fabricated Equipment index. For refractories, however, use the appropriate BLS index; the base index is #135.

Dampers

Use CE Fabricated Equipment index. For automatic dampers, use CE Process Instruments and Controls on that portion of price attributable to automatic control.

Heat Exchangers

Use CE Fabricated Equipment index.

Mechanical Collectors

Use CE Process Machinery index.

Fans, Motors, and Starters

For fans use BLS #1147. For motors use the appropriate BLS index; the base index is #1173. For starters use BLS #11750781. For V-belts use BLS #11450133.

Stacks

Use CE Fabricated Equipment index.

Cooling Tower

Use CE Fabricated Equipment index.

Pumps

Use BLS #1141 index.

Dust Removal Equipment

For screw conveyors, use the CE Fabricated Equipment index. For water treatment equipment, use the appropriate CE or BLS index, depending on the equipment component.

Operating Cost

For precipitators, scrubbers and baghouses use the following composite factor:

.1 (Table B-23, Labor Cost) + .9 (BLS #0543, Industrial Power)

For incinerators and adsorbers use the following composite factor:

.1 (Table B-23, Labor Cost) + .1 (CE Equipment, Machinery, Supports)
+ .8 (BLS #05310101, Natural Gas)

Table A-1 1% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9901	1.01000	0.990
2	0.9803	0.50751	1.970
3	0.9706	0.34002	2.941
4	0.9610	0.25628	3.902
5	0.9515	0.20604	4.853
6	0.9420	0.17255	5.795
7	0.9327	0.14863	6.728
8	0.9235	0.13069	7.652
9	0.9143	0.11674	8.566
10	0.9053	0.10558	9.471
11	0.8963	0.09645	10.368
12	0.8874	0.08885	11.255
13	0.8787	0.08241	12.134
14	0.8700	0.07690	13.004
15	0.8613	0.07212	13.865
16	0.8528	0.06794	14.718
17	0.8444	0.06426	15.562
18	0.8360	0.06098	16.398
19	0.8277	0.05805	17.226
20	0.8195	0.05542	18.046
21	0.8114	0.05303	18.857
22	0.8034	0.05086	19.660
23	0.7954	0.04889	20.456
24	0.7876	0.04707	21.243
25	0.7798	0.04541	22.023
26	0.7720	0.04387	22.795
27	0.7644	0.04245	23.560
28	0.7568	0.04112	24.316
29	0.7493	0.03990	25.066
30	0.7419	0.03875	25.808
31	0.7346	0.03768	26.542
32	0.7273	0.03667	27.270
33	0.7201	0.03573	27.990
34	0.7130	0.03484	28.703
35	0.7059	0.03400	29.409
40	0.6717	0.03046	32.835
45	0.6391	0.02771	36.095
50	0.6080	0.02551	39.196

Table A-2 2% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9804	1.02000	0.980
2	0.9612	0.51505	1.942
3	0.9423	0.34675	2.884
4	0.9238	0.26262	3.808
5	0.9057	0.21216	4.713
6	0.8880	0.17853	5.601
7	0.8706	0.15451	6.472
8	0.8535	0.13651	7.325
9	0.8368	0.12252	8.162
10	0.8203	0.11133	8.983
11	0.8043	0.10218	9.787
12	0.7885	0.09456	10.575
13	0.7730	0.08812	11.348
14	0.7579	0.08260	12.106
15	0.7430	0.07783	12.849
16	0.7284	0.07365	13.578
17	0.7142	0.06997	14.292
18	0.7002	0.06670	14.992
19	0.6864	0.06378	15.678
20	0.6730	0.06116	16.351
21	0.6598	0.05878	17.011
22	0.6468	0.05663	17.658
23	0.6342	0.05467	18.292
24	0.6217	0.05287	18.914
25	0.6095	0.0512	19.523
26	0.5976	0.04970	20.121
27	0.5859	0.04829	20.707
28	0.5744	0.04699	21.281
29	0.5631	0.04578	21.844
30	0.5521	0.04465	22.396
31	0.5412	0.04360	22.938
32	0.5306	0.04261	23.468
33	0.5202	0.04169	23.989
34	0.5100	0.04082	24.499
35	0.5000	0.04000	24.999
40	0.4529	0.03656	27.355
45	0.4102	0.03391	29.490
50	0.3715	0.03182	31.424

Table A-3 3% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9709	1.03000	0.971
2	0.9426	0.52261	1.913
3	0.9151	0.35353	2.829
4	0.8885	0.26903	3.717
5	0.8626	0.21835	4.580
6	0.8375	0.18460	5.417
7	0.8131	0.16051	6.230
8	0.7894	0.14246	7.020
9	0.7664	0.12843	7.786
10	0.7441	0.11723	8.530
11	0.7224	0.10808	9.253
12	0.7014	0.10046	9.954
13	0.6810	0.09403	10.635
14	0.6611	0.08853	11.296
15	0.6419	0.08377	11.938
16	0.6232	0.07961	12.561
17	0.6050	0.07595	13.166
18	0.5874	0.07271	13.754
19	0.5703	0.06981	14.324
20	0.5537	0.06722	14.877
21	0.5375	0.06487	15.415
22	0.5219	0.06275	15.937
23	0.5067	0.06081	16.444
24	0.4919	0.05905	16.936
25	0.4776	0.05743	17.413
26	0.4637	0.05594	17.877
27	0.4502	0.05456	18.327
28	0.4371	0.05329	18.764
29	0.4243	0.05211	19.188
30	0.4120	0.05102	19.600
31	0.4000	0.05000	20.000
32	0.3883	0.04905	20.389
33	0.3770	0.04816	20.766
34	0.3660	0.04732	21.132
35	0.3554	0.04654	21.487
40	0.3066	0.04326	23.115
45	0.2644	0.04079	24.519
50	0.2281	0.03887	25.730

Table A-4 4% COMPOUND INTEREST FACTORS

n	Single Payment Present Worth Factor P/F	Uniform Series Capital Recovery Factor A/P	Uniform Series Present Worth Factor P/A
1	0.9615	1.04000	0.962
2	0.9246	0.53020	1.886
3	0.8890	0.36035	2.775
4	0.8548	0.27549	3.630
5	0.8219	0.22463	4.452
6	0.7903	0.19076	5.242
7	0.7599	0.16661	6.002
8	0.7307	0.14853	6.733
9	0.7026	0.13449	7.435
10	0.6756	0.12329	8.111
11	0.6496	0.11415	8.760
12	0.6246	0.10655	9.385
13	0.6006	0.10014	9.986
14	0.5775	0.09467	10.563
15	0.5553	0.08994	11.118
16	0.5339	0.08582	11.652
17	0.5134	0.08220	12.166
18	0.4936	0.07899	12.659
19	0.4746	0.07614	13.134
20	0.4564	0.07358	13.590
21	0.4388	0.07128	14.029
22	0.4220	0.06920	14.451
23	0.4057	0.06731	14.857
24	0.3901	0.06559	15.247
25	0.3751	0.06401	15.622
26	0.3607	0.06257	15.983
27	0.3468	0.06124	16.330
28	0.3335	0.06001	16.663
29	0.3207	0.05888	16.984
30	0.3083	0.05783	17.292
31	0.2965	0.05686	17.588
32	0.2851	0.05595	17.874
33	0.2741	0.05510	18.148
34	0.2636	0.05431	18.411
35	0.2534	0.05358	18.665
40	0.2083	0.05052	19.793
45	0.1712	0.04826	20.720
50	0.1407	0.04655	21.482

Table A-5 5% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9524	1.05000	0.952
2	0.9070	0.53780	1.859
3	0.8638	0.36721	2.723
4	0.8227	0.28201	3.546
5	0.7835	0.23097	4.329
6	0.7462	0.19702	5.076
7	0.7107	0.17282	5.786
8	0.6768	0.15472	6.463
9	0.6446	0.14069	7.108
10	0.6139	0.12950	7.722
11	0.5847	0.12039	8.306
12	0.5568	0.11283	8.863
13	0.5303	0.10646	9.394
14	0.5051	0.10102	9.899
15	0.4810	0.09634	10.380
16	0.4581	0.09227	10.838
17	0.4363	0.08870	11.274
18	0.4155	0.08555	11.690
19	0.3957	0.08275	12.085
20	0.3769	0.08024	12.462
21	0.3589	0.07800	12.821
22	0.3418	0.07597	13.163
23	0.3256	0.07414	13.489
24	0.3101	0.07247	13.799
25	0.2953	0.07095	14.094
26	0.2812	0.06956	14.375
27	0.2678	0.06829	14.643
28	0.2551	0.06712	14.898
29	0.2429	0.06605	15.141
30	0.2314	0.06505	15.372
31	0.2204	0.06413	15.593
32	0.2099	0.06328	15.803
33	0.1999	0.06249	16.003
34	0.1904	0.06176	16.193
35	0.1813	0.06107	16.374
40	0.1420	0.05828	17.159
45	0.1113	0.05626	17.774
50	0.0872	0.05478	18.256

Table A-6 6% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/F	Present Worth Factor P/A
1	0.9434	1.06000	0.943
2	0.8900	0.54544	1.833
3	0.8396	0.37411	2.673
4	0.7921	0.28859	3.465
5	0.7473	0.23740	4.212
6	0.7050	0.20336	4.917
7	0.6651	0.17914	5.582
8	0.6274	0.16104	6.210
9	0.5919	0.14702	6.802
10	0.5584	0.13587	7.360
11	0.5268	0.12679	7.887
12	0.4970	0.11928	8.384
13	0.4688	0.11296	8.853
14	0.4423	0.10758	9.295
15	0.4173	0.10296	9.712
16	0.3936	0.09895	10.106
17	0.3714	0.09544	10.477
18	0.3503	0.09236	10.828
19	0.3305	0.08962	11.158
20	0.3118	0.08718	11.470
21	0.2942	0.08500	11.764
22	0.2775	0.08305	12.042
23	0.2618	0.08128	12.303
24	0.2470	0.07968	12.550
25	0.2330	0.07823	12.783
26	0.2198	0.07690	13.003
27	0.2074	0.07570	13.211
28	0.1956	0.07459	13.406
29	0.1846	0.07358	13.591
30	0.1741	0.07265	13.765
31	0.1643	0.07179	13.929
32	0.1550	0.07100	14.084
33	0.1462	0.07027	14.230
34	0.1379	0.06960	14.368
35	0.1301	0.06897	14.498
40	0.0972	0.06646	15.046
45	0.0727	0.06470	15.456
[illegible]	0.0543	0.06344	15.762

Table A-7 7% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9346	1.07000	0.935
2	0.8734	0.55309	1.808
3	0.8163	0.38105	2.624
4	0.7629	0.29523	3.387
5	0.7130	0.24389	4.100
6	0.6663	0.20980	4.767
7	0.6227	0.18555	5.389
8	0.5820	0.16747	5.971
9	0.5439	0.15349	6.515
10	0.5083	0.14238	7.024
11	0.4751	0.13336	7.499
12	0.4440	0.12590	7.943
13	0.4150	0.11965	8.358
14	0.3878	0.11434	8.745
15	0.3624	0.10979	9.108
16	0.3387	0.10586	9.447
17	0.3166	0.10243	9.763
18	0.2959	0.09941	10.059
19	0.2765	0.09675	10.336
20	0.2584	0.09439	10.594
21	0.2415	0.09229	10.836
22	0.2257	0.09041	11.061
23	0.2109	0.08871	11.272
24	0.1971	0.08719	11.469
25	0.1842	0.08581	11.654
26	0.1722	0.08456	11.826
27	0.1609	0.08343	11.987
28	0.1504	0.08239	12.137
29	0.1406	0.08145	12.278
30	0.1314	0.08059	12.409
31	0.1228	0.07980	12.532
32	0.1147	0.07907	12.647
33	0.1072	0.07841	12.754
34	0.1002	0.07780	12.854
35	0.0937	0.07723	12.948
40	0.0668	0.07501	13.332
45	0.0476	0.07350	13.606
50	0.0339	0.07246	13.801

Table A-8 8% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9259	1.08000	0.926
2	0.8573	0.56077	1.783
3	0.7938	0.38803	2.577
4	0.7350	0.30192	3.312
5	0.6806	0.25046	3.993
6	0.6302	0.21632	4.623
7	0.5835	0.19207	5.206
8	0.5403	0.17401	5.747
9	0.5002	0.16008	6.247
10	0.4632	0.14903	6.710
11	0.4289	0.14008	7.139
12	0.3971	0.13270	7.536
13	0.3677	0.12652	7.904
14	0.3405	0.12130	8.244
15	0.3152	0.11683	8.559
16	0.2919	0.11298	8.851
17	0.2703	0.10963	9.122
18	0.2502	0.10670	9.372
19	0.2317	0.10413	9.604
20	0.2145	0.10185	9.818
21	0.1987	0.09983	10.017
22	0.1839	0.09803	10.201
23	0.1703	0.09642	10.371
24	0.1577	0.09498	10.529
25	0.1460	0.09368	10.675
26	0.1352	0.09251	10.810
27	0.1252	0.09145	10.935
28	0.1159	0.09049	11.051
29	0.1073	0.08962	11.158
30	0.0994	0.08883	11.258
31	0.0920	0.08811	11.350
32	0.0852	0.08745	11.435
33	0.0789	0.08685	11.514
34	0.0730	0.08630	11.587
35	0.0676	0.08580	11.655
40	0.0460	0.08386	11.925
45	0.0313	0.08259	12.108
50	0.0213	0.08174	12.233

Table A-9 10% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.9091	1.10000	0.909
2	0.8264	0.57619	1.736
3	0.7513	0.40211	2.487
4	0.6830	0.31547	3.170
5	0.6209	0.26380	3.791
6	0.5645	0.22961	4.355
7	0.5132	0.20541	4.868
8	0.4665	0.18744	5.355
9	0.4241	0.17364	5.759
10	0.3855	0.16275	6.144
11	0.3505	0.15396	6.495
12	0.3186	0.14676	6.814
13	0.2897	0.14078	7.103
14	0.2633	0.13575	7.367
15	0.2394	0.13147	7.606
16	0.2176	0.12782	7.824
17	0.1978	0.12466	8.022
18	0.1799	0.12193	8.201
19	0.1635	0.11955	8.365
20	0.1486	0.11746	8.514
21	0.1351	0.11562	8.649
22	0.1228	0.11401	8.772
23	0.1117	0.11257	8.883
24	0.1015	0.11130	8.985
25	0.0923	0.11017	9.077
26	0.0839	0.10916	9.161
27	0.0763	0.10826	9.237
28	0.0693	0.10745	9.307
29	0.0630	0.10673	9.370
30	0.0573	0.10608	9.427
31	0.0521	0.10550	9.479
32	0.0474	0.10497	9.526
33	0.0431	0.10450	9.569
34	0.0391	0.10407	9.609
35	0.0356	0.10369	9.644
40	0.0221	0.10226	9.779
45	0.0137	0.10139	9.863
50	0.0085	0.10086	9.915

Table A-10 12% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.8929	1.12000	0.893
2	0.7972	0.59170	1.690
3	0.7118	0.41635	2.402
4	0.6355	0.32923	3.037
5	0.5674	0.27741	3.605
6	0.5066	0.24323	4.111
7	0.4523	0.21912	4.564
8	0.4039	0.20130	4.968
9	0.3606	0.18768	5.328
10	0.3220	0.17698	5.650
11	0.2875	0.16842	5.938
12	0.2567	0.16144	6.194
13	0.2292	0.15568	6.424
14	0.2046	0.15087	6.628
15	0.1827	0.14682	6.811
16	0.1631	0.14339	6.974
17	0.1456	0.14046	7.120
18	0.1300	0.13794	7.250
19	0.1161	0.13576	7.366
20	0.1037	0.13388	7.469
21	0.0926	0.13224	7.562
22	0.0826	0.13081	7.645
23	0.0738	0.12956	7.718
24	0.0659	0.12846	7.784
25	0.0588	0.12750	7.843
26	0.0525	0.12665	7.896
27	0.0469	0.12590	7.943
28	0.0419	0.12524	7.984
29	0.0374	0.12466	8.022
30	0.0334	0.12414	8.055
31	0.0298	0.12369	8.085
32	0.0266	0.12328	8.112
33	0.0238	0.12292	8.135
34	0.0212	0.12260	8.157
35	0.0189	0.12232	8.176
40	0.0107	0.12130	8.244
45	0.0061	0.12074	8.283
50	0.0035	0.12042	8.305

Table A-11 15% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.8696	1.15000	0.870
2	0.7561	0.61512	1.626
3	0.6575	0.43798	2.283
4	0.5718	0.35027	2.855
5	0.4972	0.29832	3.352
6	0.4323	0.26424	3.784
7	0.3759	0.24036	4.160
8	0.3269	0.22285	4.487
9	0.2843	0.20957	4.772
10	0.2472	0.19925	5.019
11	0.2149	0.19107	5.234
12	0.1869	0.18448	5.421
13	0.1625	0.17911	5.583
14	0.1413	0.17469	5.724
15	0.1229	0.17102	5.847
16	0.1069	0.16795	5.954
17	0.0929	0.16537	6.047
18	0.0808	0.16319	6.128
19	0.0703	0.16134	6.198
20	0.0611	0.15976	6.259
21	0.0531	0.15842	6.312
22	0.0462	0.15727	6.359
23	0.0402	0.15628	6.399
24	0.0349	0.15543	6.434
25	0.0304	0.15470	6.464
26	0.0264	0.15407	6.491
27	0.0230	0.15353	6.514
28	0.0200	0.15306	6.534
29	0.0174	0.15265	6.551
30	0.0151	0.15230	6.566
31	0.0131	0.15200	6.579
32	0.0114	0.15173	6.591
33	0.0099	0.15150	6.600
34	0.0086	0.15131	6.609
35	0.0075	0.15113	6.617
40	0.0037	0.15056	6.642
45	0.0019	0.15028	6.654
50	0.0009	0.15014	6.661

Table A-12 20% COMPOUND INTEREST FACTORS

	Single Payment	Uniform Series	
n	Present Worth Factor P/F	Capital Recovery Factor A/P	Present Worth Factor P/A
1	0.8333	1.20000	0.833
2	0.6944	0.65455	1.528
3	0.5787	0.47473	2.106
4	0.4823	0.38629	2.589
5	0.4019	0.33438	2.991
6	0.3349	0.30071	3.326
7	0.2791	0.27742	3.605
8	0.2326	0.26061	3.837
9	0.1938	0.24808	4.031
10	0.1615	0.23852	4.192
11	0.1346	0.23110	4.327
12	0.1122	0.22526	4.439
13	0.0935	0.22062	4.533
14	0.0779	0.21689	4.611
15	0.0649	0.21388	4.675
16	0.0541	0.21144	4.730
17	0.0451	0.20944	4.775
18	0.0376	0.20781	4.812
19	0.0313	0.20646	4.844
20	0.0261	0.20536	4.870
21	0.0217	0.20444	4.891
22	0.0181	0.20369	4.909
23	0.0151	0.20307	4.925
24	0.0126	0.20255	4.937
25	0.0105	0.20212	4.948
26	0.0087	0.20176	4.956
27	0.0073	0.20147	4.964
28	0.0061	0.20122	4.970
29	0.0051	0.20102	4.975
30	0.0042	0.20085	4.979
31	0.0035	0.20070	4.982
32	0.0029	0.20059	4.985
33	0.0024	0.20049	4.988
34	0.0020	0.20041	4.990
35	0.0017	0.20034	4.992
40	0.0007	0.20014	4.997
45	0.0003	0.20005	4.999
50	0.0001	0.20002	4.999

APPENDIX B

EQUIPMENT COST INDEXES

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES

INDEX	1975 ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CE Plant Index	182.3	179.4	179.5	180.7	180.7	180.8	181.8	182.1	181.9	183.7	185.6	185.5	186.2
Engineering & Supervision	141.8	139.6	139.8	140.2	140.7	141.1	141.6	142.0	142.4	142.9	143.3	143.7	144.2
Building	176.9	173.1	173.6	174.7	175.5	175.8	176.3	177.1	177.5	178.8	180.2	179.4	181.1
Construction Labor	168.4	166.7	164.2	167.4	166.6	165.5	167.3	168.4	168.7	171.9	172.0	171.2	171.1
Equipment, Machinery Supports	194.7	191.6	192.3	192.9	193.0	193.3	194.3	194.2	193.7	195.2	198.1	198.2	199.1
Fabricated Equipment	192.2	190.7	190.6	191.6	191.6	191.1	191.5	190.0	190.0	191.4	195.8	195.2	196.4
Process Machinery	184.7	179.1	179.9	181.4	182.5	182.8	184.7	185.5	185.1	186.3	188.8	189.6	190.9
Pipe, Valves & Fittings	217.0	209.8	212.9	212.8	213.5	217.2	217.8	216.0	216.7	219.9	221.6	222.6	223.3
Process Instruments & Controls	181.4	177.6	177.8	177.7	178.8	178.9	180.4	180.2	181.2	183.3	186.3	186.6	187.8
Pumps & Compressors	208.3	208.7	208.7	208.7	206.2	206.2	208.3	209.1	207.6	209.4	209.1	209.1	209.0
Electrical Equipment & Materials	143.0	141.5	141.7	142.4	141.4	141.8	142.0	151.5	141.6	141.8	143.1	143.7	143.3
Structural Supports Insulation & Paint	198.6	198.6	198.2	198.4	198.0	195.5	196.4	198.5	198.5	197.9	200.7	200.7	201.2

SOURCE: Chemical Engineering, Economic Indicators

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES (cont'd)

INDEX	1974 ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CE Plant Index	165.4	150.0	150.7	153.8	156.7	161.4	164.7	168.8	172.2	174.8	176.0	177.4	177.8
Engineering & Supervision	134.4	131.6	131.9	132.2	132.5	132.8	132.8	134.0	134.3	134.5	138.2	138.7	139.1
Building	165.5	156.7	156.4	158.8	162.3	164.3	165.4	167.1	170.6	172.7	170.5	172.1	172.5
Construction Labor	163.4	162.7	162.4	162.3	162.7	160.0	159.4	159.5	164.1	166.6	165.8	166.9	166.6
Equipment, Machinery Supports	171.2	147.7	149.0	153.7	157.8	166.2	171.8	178.0	181.6	184.7	186.5	188.1	188.8
Fabricated Equipment	170.1	147.3	148.7	152.7	155.1	165.1	169.3	179.0	181.4	184.0	186.0	186.1	186.8
Process Machinery	160.3	143.1	143.7	146.8	149.4	154.8	159.2	163.5	167.9	170.3	172.9	175.7	177.2
Pipe, Valves & Fittings	192.2	162.6	163.2	169.9	179.6	189.6	197.1	203.0	206.7	209.4	209.7	208.3	208.7
Process Instruments & Controls	164.7	152.0	153.4	158.2	157.2	159.7	162.7	165.8	168.2	173.2	174.1	175.2	176.9
Pumps & Compressors	175.7	144.0	145.8	150.6	157.9	168.2	175.6	182.7	186.8	187.3	195.8	206.9	206.9
Electrical Equipment & Materials	126.4	109.7	110.3	112.3	114.0	121.5	127.1	131.5	133.5	136.3	138.2	141.4	141.4
Structural Supports Insulation & Paint	172.4	145.0	147.5	155.0	158.5	165.1	173.4	173.5	180.8	188.1	187.4	191.9	192.4

SOURCE: Chemical Engineering, Economic Indicators

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES (cont'd)

INDEX	1973 ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CE Plant Index	144.1	140.8	140.4	141.5	141.8	142.4	144.5	144.6	145.0	146.4	146.7	147.5	148.2
Engineering & Supervision	122.84	112.0	112.0	122.3	122.4	112.5	129.8	130.1	130.1	130.1	130.7	130.8	131.3
Building	150.6	146.5	146.9	148.3	150.3	151.1	150.4	149.8	150.4	153.0	150.9	154.7	155.0
Construction Labor	157.9	158.9	155.8	154.8	155.0	155.4	155.6	156.3	156.3	161.8	161.7	161.6	162.0
Equipment, Machinery Supports	141.9	138.3	138.8	140.7	140.9	141.7	142.2	142.1	142.0	142.6	143.5	144.3	145.2
Fabricated Equipment	142.5	140.0	140.0	140.9	141.7	142.6	143.0	143.0	143.0	143.4	143.7	144.1	144.8
Process Machinery	137.6	134.3	134.5	135.1	137.1	137.6	137.9	137.9	138.5	139.1	139.6	140.3	142.0
Pipe, Valves & Fittings	151.3	146.1	146.1	149.2	150.1	151.1	151.7	151.8	151.8	151.8	153.9	156.6	157.8
Process Instruments & Controls	147.1	145.0	144.9	145.8	146.1	146.9	146.9	147.0	147.4	147.9	148.1	148.8	150.4
Pumps & Compressors	139.5	137.0	137.0	138.4	138.4	138.4	141.3	140.9	140.9	140.9	140.8	141.4	142.4
Electrical Equipment & Materials	104.2	100.6	100.6	102.1	103.9	104.5	105.2	105.1	105.1	105.1	105.3	106.0	107.2
Structural Supports Insulation & Paint	140.9	137.2	137.2	140.0	141.2	142.0	141.8	141.2	141.2	141.2	141.5	143.5	142.8

SOURCE: Chemical Engineering, Economic Indicators

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES (cont'd)

INDEX	1972 ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CE Plant Index	137.2	136.0	136.0	137.0	137.1	137.1	136.5	136.5	137.0	137.8	138.2	138.4	139.1
Engineering & Supervision	111.9	111.8	111.9	111.7	111.6	111.9	111.9	112.0	112.1	112.1	112.0	112.1	112.1
Building	142.0	139.8	140.0	140.7	141.4	141.6	140.3	141.4	141.9	143.0	144.1	144.5	145.0
Construction Labor	152.2	151.9	151.6	150.8	151.3	151.7	149.7	149.7	150.6	153.1	154.5	154.7	156.7
Equipment, Machinery Supports	135.4	133.8	133.9	135.8	135.3	135.5	135.4	135.2	135.6	135.9	135.9	136.0	136.5
Fabricated Equipment	136.3	135.1	136.1	137.8	136.2	135.9	135.7	135.6	136.3	135.7	136.8	136.6	137.5
Process Machinery	132.1	130.5	129.6	131.8	132.2	132.2	132.2	132.2	132.3	132.9	132.9	133.1	133.6
Pipe, Valves & Fittings	142.9	141.4	141.9	143.1	143.1	143.2	143.3	142.9	142.9	143.0	143.3	143.6	143.6
Process Instruments & Controls	143.8	141.9	142.7	143.6	143.9	144.1	144.0	144.0	144.3	144.2	144.1	144.2	144.7
Pumps & Compressors	135.9	132.4	134.4	135.7	135.7	135.7	136.3	136.6	136.7	136.7	137.7	137.0	137.0
Electrical Equipment & Materials	99.1	98.2	98.3	98.2	98.6	99.1	99.4	99.3	99.5	99.4	99.3	100.0	100.1
Structural Supports Insulation & Paint	133.6	131.2	131.9	132.1	132.7	134.9	134.1	133.8	134.2	134.4	134.5	134.5	134.6

SOURCE: Chemical Engineering, Economic Indicators

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES (cont'd)

INDEX	1971 ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CE Plant Index	132.3	128.2	129.1	129.9	130.2	131.6	131.4	132.3	134.4	135.0	135.1	134.9	135.3
Engineering & Supervision	111.4	111.1	111.2	111.2	111.3	111.4	111.3	111.4	111.4	111.5	111.6	111.6	111.7
Building	135.5	130.0	131.5	132.9	132.9	134.3	133.6	136.2	138.2	139.0	138.9	138.8	139.2
Construction Labor	146.2	142.5	143.3	142.8	142.5	144.2	144.0	146.1	147.4	149.9	150.4	150.1	150.6
Equipment, Machinery Supports	130.4	125.7	126.7	128.0	128.6	130.0	130.0	130.3	133.1	133.1	133.0	132.7	133.2
Fabricated Equipment	130.3	125.5	125.6	127.9	128.8	129.6	129.3	129.4	133.4	133.5	133.5	133.4	134.1
Process Machinery	127.1	125.4	125.7	126.3	126.5	127.1	127.6	128.4	129.4	129.5	129.4	129.4	130.4
Pipe, Valves & Fittings	137.3	131.0	132.0	132.7	133.9	137.7	137.7	138.0	141.2	141.1	140.9	140.2	140.7
Process Instruments & Controls	139.9	134.0	138.6	139.3	139.6	140.0	140.2	140.7	141.5	141.2	141.2	141.1	141.5
Pumps & Compressors	133.2	129.1	135.8	135.8	132.5	133.1	133.1	133.1	133.7	133.7	133.7	132.4	132.4
Electrical Equipment & Materials	98.7	101.1	100.2	99.2	98.8	98.5	98.1	97.9	98.6	98.3	98.3	97.7	97.7
Structural Supports Insulation & Paint	126.6	120.1	120.6	123.6	124.5	126.6	126.7	127.5	132.2	131.9	131.9	131.9	132.0

SOURCE: Chemical Engineering, Economic Indicators

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES (cont'd)

INDEX	1970 ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CE Plant Index	125.7	123.1	123.0	123.7	124.5	125.0	125.4	126.2	127.0	127.6	127.6	128.0	127.7
Engineering & Supervision	110.6	110.3	110.4	110.5	110.6	110.5	110.6	110.7	110.8	110.8	110.8	110.9	110.0
Building	127.2	125.0	124.6	124.7	125.5	126.2	126.1	127.4	128.6	130.1	130.1	129.7	129.5
Construction Labor	137.4	134.6	134.1	134.6	134.7	134.7	134.8	136.6	139.0	141.4	141.4	141.7	141.4
Equipment, Machinery Supports	123.8	120.8	120.9	122.2	123.0	123.7	124.4	124.9	125.1	125.1	125.1	125.6	125.3
Fabricated Equipment	122.7	118.5	118.8	121.1	122.2	122.5	124.0	124.1	124.2	123.8	123.8	124.0	124.8
Process Machinery	122.9	120.1	119.1	121.4	121.8	122.2	122.7	123.3	123.5	124.8	124.3	127.2	124.9
Pipe, Valves & Fittings	132.0	130.3	130.4	130.0	130.5	132.9	133.0	133.8	133.9	132.4	132.4	133.0	131.6
Process Instruments & Controls	132.1	130.6	130.8	130.9	131.2	131.5	132.0	132.0	132.6	133.6	133.6	133.7	133.7
Pumps & Compressors	125.6	123.1	123.1	123.7	124.8	124.1	124.1	125.6	125.6	129.1	129.1	129.2	129.1
Electrical Equipment & Materials	99.8	96.8	97.6	98.3	98.3	98.7	98.9	100.8	101.5	102.1	102.1	101.8	101.1
Structural Supports Insulation & Paint	117.9	114.7	114.9	116.7	117.7	118.1	118.5	118.9	118.9	119.4	119.4	118.9	119.0

SOURCE: Chemical Engineering, Economic Indicators

Table B-1 CHEMICAL ENGINEERING PLANT COST INDEXES (cont d)

INDEX	1969 ANNUAL	1968 ANNUAL	1967 ANNUAL	1966 ANNUAL	1965 ANNUAL	1964 ANNUAL	1963 ANNUAL	1962 ANNUAL	1961 ANNUAL	1960 ANNUAL	1959 ANNUAL	1958 ANNUAL	1957 ANNUAL
CE Plant Index	119.0	113.6	109.7	107.2	104.2	103.3	102.4	102.0	101.5	102.0	101.8	99.7	98.5
Engineering & Supervision	110.9	108.6	107.9	106.9	105.6	104.2	103.4	102.6	101.7	101.3	102.5	99.3	98.2
Building	122.5	115.7	110.3	107.9	104.5	103.3	102.1	101.4	100.8	101.5	101.4	99.5	99.1
Construction Labor	128.3	120.9	115.8	112.5	109.5	108.5	107.2	105.6	105.1	103.7	101.4	100.0	98.6
Equipment, Machinery Supports	116.6	111.5	107.7	105.3	102.1	101.2	100.5	100.6	100.2	101.7	101.9	99.6	98.5
Fabricated Equipment	115.1	109.9	106.2	104.8	103.4	102.7	101.7	101.0	100.1	101.2	100.9	99.6	99.5
Process Machinery	116.8	112.1	108.7	106.1	103.6	102.5	102.0	101.9	101.1	101.8	101.8	100.1	98.1
Pipe, Valves & Fittings	123.1	117.4	113.0	109.6	103.0	101.6	100.7	100.6	101.1	104.1	103.3	98.8	97.9
Process Instruments & Controls	126.1	120.9	115.2	110.0	106.5	105.8	105.7	105.9	105.9	105.4	102.9	100.4	96.7
Pumps & Compressors	119.6	115.2	111.3	107.7	103.4	101.0	100.1	101.1	100.8	101.7	102.5	100.0	97.5
Electrical Equipment & Materials	92.8	91.4	90.1	86.4	84.1	85.5	87.6	89.4	92.3	95.7	101.0	100.6	98.4
Structural Supports Insulation & Paint	112.6	105.7	102.1	101.0	98.8	98.3	97.3	99.2	99.8	101.9	101.6	100.4	98.0

SOURCE: Chemical Engineering, Economic Indicators

Table B-2 WHOLESALE PRICE INDEXES FOR COTTON BROADWOVEN GOODS, BLS # 0312, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	108.0	116.9	127.7	170.6	167.3
FEB	108.2	118.0	130.3	172.4	163.3
MAR	108.5	119.6	132.0	173.0	161.3
APR	109.0	120.5	135.8	174.8	163.9
MAY	109.8	121.5	137.8	174.7	168.6
JUN	111.0	122.9	141.8	184.4	170.6
JUL	112.1	123.3	146.2	188.5	173.7
AUG	112.2	123.1	147.7	185.4	175.7
SEP	111.6	124.4	152.0	184.6	176.6
OCT	111.6	125.2	154.4	178.3	189.2
NOV	112.1	125.7	160.6	176.0	
DEC	113.1	126.4	165.5	171.1	
ANNUAL	110.6	122.3	144.3	177.8	

Table B-3 WHOLESALE PRICE INDEXES FOR MANMADE FIBER BROADWOVEN GOODS, BLS #0334, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	94.1	111.5	124.7	159.7	146.7
FEB	94.0	112.5	125.8	161.5	144.7
MAR	94.6	112.7	133.0	161.7	128.4
APR	96.8	114.9	139.4	162..	128.3
MAY	99.2	116.6	145.3	168.3	131.6
JUN	102.4	118.0	147.7	173.4	134.5
JUL	103.6	118.6	147.1	169.2	139.9
AUG	106.0	118.4	147.8	165.3	143.1
SEP	106.1	118.2	152.8	160.7	143.1
OCT	105.1	118.3	154.9	154.6	147.1
NOV	106.7	120.3	156.6	153.4	
DEC	109.3	122.4	158.4	149.9	
ANNUAL	101.5	116.9	144.5	161.7	

Table B-4 WHOLESALE PRICE INDEXES FOR RUBBER AND PLASTIC PRODUCTS
BLS # 07, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	108.4	109.5	110.0	117.7	149.6
FEB	109.1	109.2	110.1	119.8	150.0
MAR	109.1	108.9	110.3	123.8	149.7
APR	109.0	108.7	110.6	129.4	149.4
MAY	108.7	108.8	111.5	133.7	148.9
JUN	108.7	108.9	112.6	135.6	148.6
JUL	109.7	109.2	112.9	139.5	150.1
AUG	109.8	109.5	113.1	143.4	150.0
SEP	109.7	109.5	112.8	145.6	150.8
OCT	109.5	109.5	114.0	147.5	151.5
NOV	109.5	109.8	114.8	148.5	
DEC	109.4	109.8	116.5	149.4	
ANNUAL	109.2	109.3	112.4	136.2	

Table B-5 WHOLESALE PRICE INDEXES FOR CARBON STEEL PLATES, A36
BLS # 10130246, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	119.0	141.0	146.7	152.1	212.9
FEB	119.0	141.0	146.7	152.1	212.9
MAR	128.8	141.0	146.7	161.3	212.9
APR	128.8	141.0	146.7	161.3	212.9
MAY	128.8	141.0	146.7	173.3	212.9
JUN	128.8	141.0	146.7	173.4	212.9
JUL	128.8	141.0	146.7	199.7	208.9
AUG	141.0	141.0	146.7	199.7	207.8
SEP	141.0	141.0	146.7	201.7	207.8
OCT	141.0	141.0	146.7	201.7	213.8
NOV	141.0	141.0	146.7	201.7	
DEC	141.0	141.0	146.7	201.7	
ANNUAL	132.3	141.0	146.7	181.6	

Table B-6 WHOLESALE PRICE INDEXES FOR STAINLESS STEEL PLATE BLS # 10130247, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	140.2	146.1	132.8	134.2	197.1
FEB	140.2	146.1	132.8	134.3	195.7
MAR	140.2	121.3	132.8	139.2	195.7
APR	140.2	121.3	132.8	145.5	195.7
MAY	140.2	121.3	132.8	157.7	195.7
JUN	148.1	121.3	132.8	166.0	195.7
JUL	148.1	121.3	132.8	169.2	195.7
AUG	148.1	127.6	132.8	187.8	195.7
SEP	148.1	127.6	132.8	190.4	195.7
OCT	148.1	127.6	132.8	193.0	195.7
NOV	148.1	127.6	132.8	193.0	206.3
DEC	146.1	127.6	132.8	193.0	
ANNUAL	144.6	128.1	132.8	166.9	

Table B-7 WHOLESALE PRICE INDEXES FOR CARBON STEEL SHEET, BLS #10130262, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	119.5	124.1	134.5	137.5	189.1
FEB	119.5	134.5	134.5	137.5	189.1
MAR	119.5	134.5	134.5	142.0	189.1
APR	119.5	134.5	134.5	146.6	189.1
MAY	119.5	134.5	134.5	155.8	185.0
JUN	119.5	134.5	134.5	165.4	185.0
JUL	127.5	134.5	134.5	182.3	184.8
AUG	127.5	134.5	134.5	188.5	184.8
SEP	127.5	134.5	134.5	188.5	184.8
OCT	127.5	134.5	137.5	188.5	197.0
NOV	127.5	134.5	137.5	188.5	
DEC	127.5	134.5	137.5	190.0	
ANNUAL	123.5	133.6	135.3	167.6	

Table B-8 WHOLESALE PRICE INDEXES FOR STAINLESS STEEL SHEET

BLS # 10130264, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	130.8	137.1	117.5	126.8	178.9
FEB	130.8	137.1	117.5	128.6	169.6
MAR	130.8	138.1	117.5	134.9	169.3
APR	130.8	138.1	117.5	140.1	169.3
MAY	130.8	138.1	123.4	153.6	169.3
JUN	138.1	120.4	124.5	159.6	162.6
JUL	138.1	120.4	124.5	163.9	162.9
AUG	138.1	117.5	124.5	173.1	162.9
SEP	138.1	117.5	124.5	174.9	162.9
OCT	138.1	117.5	124.5	174.9	162.4
NOV	138.1	117.5	124.6	175.8	
DEC	137.1	117.5	124.6	178.9	
ANNUAL	135.0	126.4	122.1	157.1	

Table B-9 WHOLESALE PRICE INDEXES FOR PUMPS, COMPRESSORS, AND EQUIPMENT

BLS # 1141, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	119.3	122.4	125.0	132.1	180.5
FEB	120.0	123.2	125.1	133.4	184.3
MAR	120.5	123.5	125.2	135.5	184.4
APR	121.6	123.5	125.9	138.7	186.2
MAY	121.9	123.0	126.2	142.5	187.3
JUN	121.9	124.2	127.7	147.7	187.3
JUL	121.9	124.9	127.5	154.0	187.9
AUG	122.3	124.6	127.7	162.7	188.8
SEP	122.3	124.6	127.6	163.8	189.2
OCT	122.6	124.7	128.6	168.8	189.9
NOV	122.2	124.8	131.4	176.8	
DEC	122.2	124.8	131.7	179.5	
ANNUAL	121.6	124.0	127.5	153.0	

Table B-10 WHOLESALE PRICE INDEXES FOR V-BELT SHEAVES

BLS # 11450133, 1976=100

MONTH	1971	1972	1973	1974	1975
JAN	117.6	117.6	126.3	130.4	175.4
FEB	117.6	117.6	126.3	133.3	175.4
MAR	117.6	117.6	126.3	133.3	175.4
APR	117.6	122.4	126.3	133.3	175.4
MAY	117.6	124.4	126.3	137.7	174.1
JUN	117.6	126.3	126.3	139.9	174.1
JUL	117.6	126.3	126.3	150.9	174.1
AUG	117.6	126.3	126.3	162.6	172.8
SEP	117.6	126.3	126.3	162.6	172.8
OCT	117.6	126.3	126.3	171.6	172.8
NOV	117.6	126.3	128.2	171.6	
DEC	117.6	126.3	130.4	175.4	
ANNUAL	117.6	123.6	126.8	150 2	

Table B-11 WHOLESALE PRICE INDEXES FOR FANS AND BLOWERS, EXCEPT PORTABLE

BLS # 1147, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	120.8	125.6	132.4	138.2	197.9
FEB	121.0	127.3	132.6	138.5	198.2
MAR	123.1	128.6	133.1	145.5	198.6
APR	122.2	128.8	134.4	146.4	198.8
MAY	122.2	128.8	134.4	158.6	201.3
JUN	124.6	128.8	135.0	171.8	202.4
JUL	124.9	128.8	135.0	178.6	205.4
AUG	124.9	128.8	135.2	183.2	205.4
SEP	125.3	129.9	137.5	185.3	205.8
OCT	125.3	130.0	137.7	188.6	206.4
NOV	125.3	130.0	137.6	192.3	
DEC	125.5	122.4	137.6	192.6	
ANNUAL	123.8	129.0	135.2	168.3	

Table B-12 WHOLESALE PRICE INDEXES FOR MOTORS, INTEGRAL HORSEPOWER, A.C., 10 HP BLS # 11730112, 1967=100

MONTH	1971	1972	1972	1974	1975
JAN	122.1	99.6	112.1	125.8	184.0
FEB	113.6	99.6	112.1	125.8	186.1
MAR	109.1	99.6	115.2	127.9	186.1
APR	104.0	101.1	118.2	130.9	186.1
MAY	104.0	105.6	119.7	134.9	186.1
JUN	104.0	105.6	120.9	155.1	N/A
JUL	102.2	105.6	120.9	160.0	N/A
AUG	101.6	105.6	120.9	161.7	186.1
SEP	101.6	105.6	119.7	167.6	186.1
OCT	101.6	105.6	119.7	172.4	186.1
NOV	101.6	111.5	121.8	175.9	
DEC	101.6	111.5	124.2	179.8	
ANNUAL	105.6	104.7	118.8	151.5	

N/A = Not Available

Table B-13 WHOLESALE PRICE INDEXES FOR MOTORS, INTEGRAL HORSEPOWER, A.C., 250 HP BLS # 11730113, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	123.9	125.1	129.5	142.0	
FEB	123.9	125.1	129.5	143.9	
MAR	123.9	125.1	131.9	143.9	
APR	125.6	127.8	136.3	141.3	
MAY	129.0	127.8	136.3	N/A	
JUN	129.0	127.8	136.3	N/A	
JUL	130.7	127.8	139.3	N/A	
AUG	130.7	129.5	139.3	N/A	
SEP	130.7	129.5	139.3	N/A	
OCT	130.7	129.5	139.3	N/A	
NOV	130.7	129.5	139.3	N/A	
DEC	130.7	129.5	139.3	N/A	
ANNUAL	128.3	127.8	136.3	142.8	

N/A = Not Available

Table B-14 WHOLESALE PRICE INDEXES FOR MOTORS, INTEGRAL HORSEPOWER, A.C., 50 HP BLS # 11730119, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	115.1	99.6	111.5	123.5	178.0
FEB	98.9	99.6	111.5	123.5	180.6
MAR	98.9	99.6	113.4	126.1	184.9
APR	98.2	101.5	117.1	126.1	184.9
MAY	98.2	105.6	119.0	140.7	184.9
JUN	98.2	105.6	120.5	152.4	184.9
JUL	95.9	105.6	120.5	160.9	184.9
AUG	95.2	105.6	120.5	163.1	184.9
SEP	95.2	105.6	119.0	164.3	184.9
OCT	95.2	105.6	119.0	172.8	184.9
NOV	95.2	111.5	119.0	172.8	
DEC	95.2	111.5	120.1	172.8	
ANNUAL	98.3	104.7	117.6	149.9	

Table B-15 WHOLESALE PRICE INDEXES FOR A.C. STARTERS, 75 HP, 440 VOLTS BLS #11750781, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	106.8	112.4	112.4	115.4	143.7
FEB	105.5	112.4	112.4	116.1	143.7
MAR	105.5	112.4	112.4	116.1	143.7
APR	105.5	112.4	112.4	116.1	143.7
MAY	105.5	112.4	112.4	123.4	143.7
JUN	105.5	112.4	112.4	130.0	143.7
JUL	105.7	112.4	112.4	132.0	143.7
AUG	112.4	112.4	112.4	132.0	143.7
SEP	112.4	112.4	112.4	133.0	147.0
OCT	112.4	112.4	112.4	141.0	N/A
NOV	112.4	112.4	112.4	143.7	
DEC	112.4	112.4	112.4	143.7	
ANNUAL	108.5	112.4	112.4	128.5	

Table B-16 WHOLESALE PRICE INDEXES FOR REFRACTORIES

BLS # 135, 1967=100; for 1975, Dec '74=100

MONTH	1971	1972	1973	1974	1975
JAN	126.7	127.1	136.3	136.3	100.4
FEB	126.7	127.1	136.3	136.3	103.2
MAR	126.7	127.1	136.3	136.3	103.5
APR	126.7	127.1	136.3	136.3	103.7
MAY	126.7	127.1	136.3	136.3	103.9
JUN	126.9	127.1	136.3	136.3	103.9
JUL	126.9	127.1	136.3	137.8	103.8
AUG	126.9	129.6	136.3	137.8	104.1
SEP	126.9	132.1	136.3	153.4	104.6
OCT	127.1	132.1	136.3	157.0	104.7
NOV	127.1	132.1	136.3	157.8	
DEC	127.1	132.1	136.3	160.5	
ANNUAL	126.9	129.0	136.3	143.5	

Table B-17 WHOLESALE PRICE INDEXES FOR FIRE CLAY BRICK, SUPER DUTY

BLS # 13520111, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	129.0	129.0	134.5	134.5	167.1
FEB	129.0	129.0	134.5	134.5	170.3
MAR	129.0	129.0	134.5	134.5	170.3
APR	129.0	N/A	134.5	134.5	170.3
MAY	129.0	N/A	N/A	134.5	170.3
JUN	129.0	N/A	134.5	134.5	170.3
JUL	129.0	129.0	N/A	135.3	170.3
AUG	129.0	131.0	N/A	N/A	170.3
SEP	129.0	132.3	134.5	156.0	170.3
OCT	129.0	N/A	134.5	164.2	170.3
NOV	129.0	132.3	134.5	164.2	
DEC	129.0	132.3	N/A	167.1	
ANNUAL	129.0	130.5	134.5	144.9	

N/A = Not Available

Table B-18 WHOLESALE PRICE INDEXES FOR HIGH ALUMINA BRICK, 70 PCT.
BLS # 13520131, 1967=100

MONTH	1971	1972	1973	1974	1974
JAN	119.8	122.7	146.9	146.9	183.4
FEB	119.8	122.7	146.9	146.9	189.0
MAR	119.8	122.7	146.9	146.9	189.0
APR	119.8	N/A	146.9	146.9	190.1
MAY	119.8	N/A	N/A	146.9	190.1
JUN	121.5	N/A	146.9	146.9	190.1
JUL	121.5	122.7	N/A	154.6	190.1
AUG	121.5	130.4	N/A	N/A	192.4
SEP	121.5	134.5	146.9	170.4	192.4
OCT	122.7	N/A	146.9	178.7	192.4
NOV	122.7	134.5	146.9	178.7	
DEC	122.7	134.5	N/A	181.2	
ANNUAL	121.1	128.1	146.9	158.6	

N/A = Not Available

Table B-19 WHOLESALE PRICE INDEXES FOR CASTABLE REFRACTORIES
BLS # 13520151, DEC 1974=100

MONTH	1975
JAN	100.8
FEB	100.8
MAR	100.8
APR	101.9
MAY	101.9
JUN	101.9
JUL	101.9
AUG	102.7
SEP	102.7
OCT	102.7
NOV	
DEC	

Table 20 WHOLESALE PRICE INDEXES FOR INSULATION MATERIALS BLS #1392, 1967=100

MONTH	1971	1972	1973	1974	1975
JAN	126.2	134.5	137.5	139.2	189.7
FEB	126.2	134.5	137.5	139.2	189.7
MAR	126.2	134.5	138.4	139.2	189.7
APR	126.2	134.5	138.4	139.9	189.7
MAY	134.5	142.7	138.4	146.9	189.7
JUN	134.5	138.8	138.4	149.8	194.1
JUL	134.5	136.8	138.4	152.0	203.0
AUG	134.5	136.8	138.4	156.0	203.0
SEP	134.5	137.5	135.0	169.6	201.4
OCT	134.5	137.5	135.0	169.6	201.4
NOV	134.5	137.5	135.0	187.2	
DEC	134.5	137.5	137.9	189.2	
ANNUAL	131.7	136.9	137.4	150.5	

Table B-21 WHOLESALE PRICE INDEXES FOR NATURAL GAS BLS # 05310101, 1967 = 100

MONTH	1971	1972	1973	1974	1975
JAN	109.5	116.3	125.1	140.9	180.5
FEB	107.9	116.6	125.4	145.0	190.5
MAR	109.7	117.6	125.8	147.8	190.0
APR	110.8	119.6	127.4	148.4	205.8
MAY	112.2	120.3	129.1	149.8	222.0
JUN	113.0	120.2	130.1	151.7	219.7
JUL	113.2	120.6	131.1	152.6	228.3
AUG	112.6	122.1	133.3	154.3	223.1
SEP	114.2	122.8	135.8	159.8	229.4
OCT	114.7	123.9	135.9	162.1	229.5
NOV	114.7	125.9	135.4	173.1	225.7
DEC	113.5	126.2	141.5	175.3	239.5
ANNUAL	112.2	121.0	131.3	155.1	215.3

Table B-22 WHOLESALE PRICE INDEXES FOR INDUSTRIAL POWER, 500 KWD

BLS # 0543, Dec 1970 = 100

MONTH	1971	1972	1973	1974	1975
JAN	111.2	121.2	126.9	142.3	198.3
FEB	111.8	122.7	129.0	147.0	202.7
MAR	112.5	122.5	130.1	154.3	208.0
APR	114.2	123.0	131.0	158.8	212.5
MAY	114.6	123.9	131.5	166.8	208.7
JUN	115.2	124.0	131.2	174.1	206.0
JUL	115.4	124.3	131.8	178.1	207.5
AUG	117.0	124.4	132.0	182.2	210.5
SEP	118.5	124.9	134.0	185.2	213.7
OCT	118.4	125.4	135.6	191.0	215.8
NOV	118.3	125.4	137.3	193.2	217.2
DEC	118.5	125.6	140.3	195.1	215.2
ANNUAL	115.5	123.9	132.6	172.3	209.7

Table B-23 INDEXES OF AVERAGE HOURLY EARNINGS: MANUFACTURING

1967 = 100

MONTH	1971	1972	1973	1974	1975
JAN		132.1	139.5	148.7	164.8
FEB		132.7	139.7	149.6	166.1
MAR		133.2	140.4	150.6	167.7
APR		133.6	141.1	151.7	168.6
MAY		134.5	141.8	153.5	169.7
JUN		135.0	142.7	155.5	171.0
JUL		135.5	143.7	156.6	172.2
AUG		136.1	144.5	158.0	173.3
SEP		136.8	145.4	159.6	174.5
OCT	129.3	137.5	146.5	161.3	176.0
NOV	129.0	138.0	147.0	162.5	177.0
DEC	131.3	138.8	147.9	163.7	177.4
ANNUAL	127.5	135.4	143.6	156.0	171.5

SOURCE: U.S. Dept. of Commerce, Survey of Current Business

APPENDIX C

GUIDE TO REFERENCES TO THE 27 INDUSTRIES

LIST OF REFERENCES CROSS-INDEXED TO INDUSTRY SOURCE

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Conical Incinerators	5, 15, 26, 113, 116, 117
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Detergent Manufacturing	5, 10, 24
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Feed Mills	5, 10, 24, 26, 35, 78, 80, 117, 118
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Glass Manufacturing	24, 36, 117
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130	Arnold, T. H. and Chilton, C. H., New Index Shows Plant Cost Trends, *Chemical Engineering*, Feb. 18, 1963, pp. 143-149.		
131	Economic Indicators, *Chemical Engineering*, Every Issue.		

APPENDIX D

GUIDE TO ASSOCIATIONS FOR THE 27 INDUSTRIES

ASSOCIATIONS

1.	Air Pollution Control Association 4400 Fifth Avenue Pittsburgh, Pennsylvania 15213	Lewis H. Rogers Executive Vice President 412/621-1100
2.	Brick Institute of America 1750 Old Meadow Road McLean, Virginia 22101	R. W. Otterson Executive Vice President 703/893-4010
3.	Refractories Institute (Brick) 1102 One Oliver Plaza Pittsburgh, Pennsylvania 15222	Bradford S. Tucker Executive Secretary 412/281-6787
4.	Refractories and Reactive Metals Association P. O. Box 2054 Princeton, New Jersey 08540	Kempton H. Roll Executive Director 609/799-3300
5.	American Boiler Manufactures Association Suite 317, AM Building 1500 Wilson Boulevard Arlington, Virginia 22209	W. B. Marx Executive Director 703/522-7298
6.	National Grain and Feed Association 501 Folger Building Washington, D. C. 20005	Alvin E. Oliver Executive Vice President 202/783-2024
7.	Grain Elevator and Processing Society 2144 Board of Trade Building Chicago, Illinois 60604	Dean M. Clark Secretary-Treasurer 312/922-3111
8.	American Feed Manufactures Association 1701 N. Fort Myer Drive Arlington, Virginia 22209	Oakley M. Ray President 703/524-0810
9.	Midwest Feed Manufacturers Association 521 E. 63rd Street Kansas City, Missouri 64110	Rex Parsons Executive Vice President 816/444-6240
10.	American Glassware Association c/o Organized Service Corp. Managers One Stone Place Bronxville, New York 10708	Donald V. Reed Managing Director 914/779-9602

11. Associated Glass and Pottery Manufacturers c/o Harold L. Hayes Brush Pottery Company P. O. Box 2576 Zanesville, Ohio 43701	Harold L. Hayes Secretary 614/454-1216
12. National Association of Manufacturers of Pressed and Blown Glassware c/o John H. Morris 707 Winmar Place Westerville, Ohio 43081	
13. Sealed Insulating Glass Manufactures Association 202 S. Cook Street Barrington, Illinois 60010	Warren W. Findling Executive Vice President 312/381-8989
14. Gray and Ductile Iron Founders' Society Cast Metals Federation Building 20611 Center Ridge Road Rocky River, Ohio 44116	Donald H. Workman Executive Vice President 216/333-9600
15. Malleable Founder's Society 20611 Center Ridge Road Cast Metals Building Rocky River, Ohio 44116	Lowell D. Ryan Executive Vice President
16. Non-Ferrous Founder's Society 21010 Center Ridge Road Cleveland, Ohio 44116	Benjamin J. Imburgia Executive Secretary 216/333-2072
17. Steel Founder's Society of America 20611 Center Ridge Road Cast Metals Federation Building Rocky River, Ohio 44116	Jack McNaughton Executive Vice President 216/333-9600
18. Foundry Equipment Manufacturers Association 1000 Vermont Avenue Washington, D. C. 20005	Charles E. Perry Executive Secretary 202/628-4634
19. American Iron and Steel Institute 150 East 42nd Street New York, New York 10017	John P. Roche President 212/697-5900

20.	Ductile Iron Society P. O. Box 22058 Cleveland, Ohio 44122	James H. Lansing Executive Director 216/752-0521
21.	Roll Manufacturers Institute 1808 Investment Building Fourth Avenue Pittsburgh, Pennsylvania 15222	A. G. Karp Executive Secretary-Treasurer 412/281-0908
22.	National Council of the Paper Industry for Air and Stream Improvement 260 Madison Avenue New York, New York 10016	Ernest J. Bolduc, Jr. Executive Director
23.	American Paper Institute 260 Madison Avenue New York, New York 10016	Albert S. Thomas Secretary-Streasurer 212/889-6200
24.	Paper Industry Management Association 2570 Devon Avenue Des Plaines, Illinois 60018	H. Mac Gregor Tuttle Executive Director 312/774-6797
25.	Technical Association of the Pulp and Paper Industry One Dunwoody Park Atlanta, Georgia 30341	Phillip E. Nethercut Executive Secretary-Treasurer 404/457-6352
26.	National Lime Association 5010 Wisconsin Avenue, N.W., Washington, D.C. 20016	Robert S. Boynton Executive Director 202/966-3418
27.	National Crushed Stone Association 1415 Elliot Place, N.W. Washington, D.C. 20007	W. L. Carter President 202/333-1536
28.	Portland Cement Association Old Orchard Road Skokie, Illinois 60076	Robert D. MacLean President 312/966-6200
29.	Fertilizer Industry Round Table Glenn Arm, Maryland 21057	Paul J. Prosser Secretary-Treasurer 301/592-6271
30.	The Fertilizer Institute 1015 18th St. N.W. Washington, D.C. 20036	Edwin M. Wheeler President 202/466-2700

31.	Eastern States Blast Furnace and Coke Oven Association c/o Paul F. Ross Bethlehem Steel Corporation Johnstown, Pa. 15907	
32.	National Coal Association 1130 17th St. N.W. Washington, D.C. 20036	Carl E. Bagge President 202/628-4322
33.	Soap and Detergent Association 475 Park Avenue South New York, New York 10016	Theodore E. Brenner President 212/725-1262
34.	Manufacturing Chemists Association 1825 Connecticut Avenue, N.W. Washington, D.C. 20009	William T. Driver President 202/483-6126
35.	American Petroleum Institute 1801 K Street, N.W. Washington, D.C. 20006	Frank N. Ikard President 202/833-5600
36.	Coordinating Research Council 30 Rockefeller Plaza New York, New York 10020	M. K. McLeod, Manager 212/757-1295
37.	Independant Refiners Association of America 1801 K Street, N.W., Suite 1101 Washington, D.C. 20006	Edwin Jason Dryer General Counsel 202/466-2340
38.	National Petroleum Refiners Association 1725 De Sales Street, N.W. Suite 802 Washington, D.C. 20036	Donald C. O'Hara Executive Vice President 202/638-3722
39.	Western Oil and Gas Association 602 S. Grand Avenue Los Angeles, California 90017	Harry Morrison Vice President 213/624-6386
40.	Copper Development Association 405 Lexington Avenue 57th Floor New York, New York 10017	George M. Hartley President 212/867-6500
41.	Copper Institute 50 Broadway New York, New York 10004	H. Fasting Secretary 212/944-1870

42.	Aluminum Association 750 Third Avenue New York, New York 10017	S. L. Goldsmith, Jr. Executive Vice President 212/972-1800
43.	Incinerator Institute of America 2425 Wilson Blvd. Arlington, Virginia 22201	Charles N. Sumwalt, Jr. Executive Director 703/528-0663
44.	American Public Works Association 1313 East 60th Street Chicago, Illinois 60637	Robert D. Bugher Executive Director 312/324-3400
45.	National Solid Wastes Management Association 1730 Rhode Island Avenue, N.W. Suite 800 Washington, D.C. 20036	
46.	Conference of State Sanitary Engineers Statehouse Charleston, West Virginia 25305	304/348-2970
47.	American Society of Sanitary Engineering 960 Illuminating Building Cleveland, Ohio 44113	Sanford Schwartz Secretary 216/696-3228
48.	National Cotton Ginner's Association Box 120 Maypearl, Texas 76064	Peary Wilemon Secretary-Treasurer 214-435-2741
49.	The Cotton Foundation 1918 North Parkway Memphis, Tennessee 38112	George S. Buck, Jr. Executive Vice President
50.	Cotton Incorporated 1370 Avenue of the America's New York, New York 10019	J. Dukes Wooters, Jr. President 212/586-1070
51.	National Cotton Council of America 1918 North Parkway Memphis, Tennessee 38112	Albert B. Russell Executive Vice President and Secretary 901/276-2783

APPENDIX E

CONVERSION FACTORS TO SI MEASUREMENTS

For a complete description of conversion factors to the International System of Units (SI), the reader is referred to the "Metric Practice Guide," American Society for Testing and Materials, pub. #E 380-72, approved by the American National Standards Institute, Std. #Z210.1-1973. The following are selected conversion factors that will accomodate all units found in this document, as well as other pertinent units. They are arranged alphabetically.

To convert from	to	Multiply by
atmosphere (normal=760 torr)	pascal (Pa)	$1.01325 * 10^5$
British thermal unit [+](Btu)	joule (J)	$1.05506 * 10^3$
Btu/ft^2	joule/metre^2 (J/m^2)	$1.13565 * 10^4$
Btu/hour	watt (W)	0.29307
Btu/pound-mass	joule/kilogram- (J/kg)	$2.326 * 10^3$
Btu/lbm·deg F (heat capacity)	joule/kilogram-kelvin (J/kg·K)	$4.18680 * 10^3$
Btu/s·ft^2·deg F	watt/metre^2-kelvin (W/m^2·K)	$2.04418 * 10^4$
calorie (International Table)	joule (J)	4.18680
day	second (s)	$8.64000 * 10^4$
degree Celsius (C)	kelvin (k)	$t_k=t_c + 273.15$
degree Fahrenheit (F)	degree Celsius	$t_c =(t_f-32)/1.8$
degree Fahrenheit (F)	kelvin (k)	$t_k= (t_f+459.67)/1.8$
foot (ft)	metre (m)	0.30480
foot^2 (ft^2)	metre^2 (m^2)	$9.29030 * 10^{-2}$
foot^3 (ft^3)	metre^3 (m^3)	$2.83168 * 10^{-2}$
foot/hour (fph)	metre/second (m/s)	$8.46667 * 10^{-5}$

[+] The Btu quantity used herein is that based on the International Table.

To convert from	to	Multiply by
foot/minute (fpm)	metre/second (m/s)	$5.08000 * 10^{-3}$
foot/second (fps)	metre/second (m/s)	0.30480
foot^3/minute (cfm)	metre^3/second (m^3/s)	$4.71947 * 10^{-4}$
foot^3/second (cfs)	metre^3/second (m^3/s)	$2.83168 * 10^{-2}$
gallon (U.S. liquid) (gal)	metre^3 (m^3)	$3.78541 * 10^{-3}$
gallon (U.S. liquid)/day (gpd)	metre^3/second (m^3/s)	$4.38126 * 10^{-8}$
gallon (U.S. liquid)/minute (gpm)	metre^3/second (m^3/s)	$6.30902 * 10^{-5}$
grain (gr)	kilogram(kg)	$6.47989 * 10^{-5}$
horsepower (hp)	watt (w)	$7.46000 * 10^{2}$
hour (hr)	second(s)	$3.60000 * 10^{3}$
inch (in)	metre (m)	$2.54000 * 10^{-2}$
inch^2 (in^2)	metre^2 (m^2)	$6.45160 * 10^{-4}$
inch of water (60F)	pascal (Pa)	$2.4884 * 10^{2}$
kilowatt-hour (kwh)	joule (J)	$3.60000 * 10^{6}$
minute (min)	second (s)	60.000
parts per million (ppm)	milligram/metre^3 (mg/m^3)	(molecular weight)/24.5
pound-force (lbf avoirdupois)	newton (N)	4.44822
pound-force/inch^2 (psi)	pascal (Pa)	$6.89476 * 10^{3}$
pound-mass (lbm avoirdupois)	kilogram (kg)	0.453592
pound-mass/foot^3 (lbm/ft^3)	kilogram/metre^3 (kg/m^3)	$1.60185 * 10^{1}$
pound-mass/minute (lbm/min)	kilogram/second (kg/s)	$7.55987 * 10^{-3}$
pound-mass/second (lbm/sec)	kilogram/second (kg/s)	$4.53592 * 10^{-1}$
ton (cooling capacity)	Btu/hr	$1.2000 * 10^{4}$
ton (short, 2000 lbm)	kilogram (kg)	$9.07185 * 10^{2}$